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Bibliometrics of Basic Research

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Bibliometric Measures of Basic Research

As part of its project "Basic Research for the 1990s" OTA is attempting to construct an information baseline on the scientific research enterprise in the U.S. This baseline will be used to assess developments in the coming decade. One tool for measuring the outcomes of basic research is bibliometrics - the statistical analysis of scientific publications. Since the publication of results in science usually comes after the completion of some amount research, bibliometrics deals with the outcomes of research rather than its support or inputs.

Publications are an especially appropriate measure for basic research because one of the main concerns of basic researchers is to gain credit and recognition for their work, and the principal way that such recognition is gained is through publication in the open literature. Communicating the results of scientific research to colleagues through publication is also considered to be an important, if not essential, feature of good research practice.(1)

Intrinsic to scientific publication is the citing or referencing of earlier published work on which the current work is based or which the current work utilizes in some way. Citation is one of the principal mechanisms for recognizing the work of others for its utility or relevance to your work. References are a common feature of scientific publications, and by counting how often publications are cited, bibliometrics can arrive at a weighted measure of publication output, which counts not only whether publications have been produced but what impact those publications have had on the work of other scientists.(2)

In order to carry out bibliometric analyses it is necessary to have a large bibliographic database in electronic form. Citation analyses further require that the bibliographic references from the scientific papers are also included in the electronic record. Citation databases should cover multiple disciplines, countries, and have chronological depth. Such is the case with the citation indexes of the Institute for Scientific Information (ISI). The present study utilizes files derived from the ISI databases.

Two ISI files are used in this study. The first is called ISI's Science Indicators File. The ISI Science Indicators File is a specially constructed multi-year file of publications from ISI's Science Citation Index which contains a citation count time series for each paper in the file. The Science Indicators File used in this study covers the years 1973 through 1988 inclusive, and contains all publications in ISIs Science Citation Index which have been cited one or more times.(3)

The second file or set of files used was the ISI Research Front database. These files are generated once a year after completion of a full year of new citation data. Highly cited items are identified and linked together by co-citation, the

joint citation of two earlier publications by a later one. A clustering routine is used to form groups of highly cited papers called research fronts.(4) Such fronts reflect active areas of research in the year from which the citations are drawn. In this study we use clusters or research fronts based on the 1989 citation database at ISI.

Our project involved two general tasks: First, to generate bibliometric profiles for U.S. academic institutions which would reflect changes in the impact of basic research carried out at these institutions; second, to devise new kinds of bibliometric indicators which would help characterize the basic research enterprise in the U.S. In carrying out the first task the ISI Science Indicators file was used. For the second task both the Science Indicators file and the Research Front files were used.

Task 1: Analyses of Academic Institutions

a. Top 100 U.S. Academic Institutions

In the first part of this task we set out to find the 100 most significant academic institutions in the US in terms of the number of scientific papers produced and the number of citations to those papers. This requires that we take a global view of the database at the institutional level. First a printout was prepared which listed each institution in the Science Indicators database from 1973 through 1988 with its total number of cited papers, the total citations received by all papers associated with each institution, and the ratio of number of citations to the number of publications, namely the average citations per cited paper.

By inspection of this printout, ranked by the average citations per paper, we identified all U.S. academic institutions have 1,000 or more publications cited one or more times in the period 1973 through 1988. It was necessary to scan down to a average citations per paper of 10.0 to obtain 100 U.S. academic institutions. Applying these two thresholds gives the institutions shown in Table 1. This table lists the institutions in alphabetic order, giving the number of cited papers, citations, and average citations per cited paper. As noted above, uncited papers are not included in the file.

We also wanted to measure whether these highly cited institutions had increased or decreased in citation over the period. We thus generated a subset of the Science Indicators file consisting of the eight most recent years, 1981 through 1988. Similar publication and citation statistics were then generated for each of the previously identified institutions for this eight year period. These data are shown in Table 2. Clearly the publication and citation counts are lower now since we are cumulating over an eight rather than a 16 year period.

In order to study change in an institution's citation impact (mean citations per paper) two approaches were taken. The first

is the change in rank within the top 100, using citation impact as the ranking criterion. Hence, we are comparing a ranking based on a 16 year cumulative record (1973 through 1988) with a ranking based on the most recent eight years of that 16 year period. Sorting in descending order by change in rank gives the institutions with the largest increases in rank first and those with the largest decreases in rank last (see Table 3).

Another measure of change was also used, namely the percent change in impact from the 16 year period to the eight year period for each institution. We know that the 16 year impact is in general larger than the eight year impact. If they are close in magnitude and the percent change is small, this indicates that the institution has a strong record in the latter one-half of the 16 year period. A high percent change indicates a decrease in impact for the most recent eight year period. In other words, the largest increases are found by looking for the smallest decreases. Sorting in ascending sequence on this percent change places the institutions with the largest increases in impact on top and the ones with the largest decreases on the bottom (see Table 4). The rankings of Table 3 and Table 4 are very similar especially at the top and bottom of the lists.

Taking this sample of 100 U.S. academic institutions, some observations can be made regarding their overall performance relative to the average U.S. paper in ISI's Science Indicators file. For the 16 year period 1973 through 1988, the average U.S. paper received 14.1 citations. Thus, 39 of the 100 institutions are above this overall U.S. average for the period. In the period 1981 through 1988 the average U.S. paper received 9.5 citations. Again exactly 39 institutions are above this average, and we can therefore conclude that there has been no net increase or decrease in the citation impact of this sample of institutions as a group, even though individual institutions have moved up or down in the rankings.

Table 1

Top 100 US Academic Institutions by Citation Impact: 1973-1988

d#	NAME	ARTICLES	CITATIONS	MEAN
1	Baylor Univ	13056	207781	15.91
2	Boston Univ	10421	161868	15.53
3	Brandeis Univ	3645	79903	21.92
4	Brigham Young Univ	1871	19193	10.26
5	Brown Univ	7860	106517	13.55
6	Calif Inst Tech (Caltech)	16160	360660	22.32
7	Carnegie Mellon Univ	4864	68218	14.02
8	Case Western Reserve	12194	165957	13.61
9	City Univ New York (CUNY)	15105	192131	12.72
10	College William and Mary	1024	10853	10.60
11	Colorado State Univ	7896	83886	10.62
12	Columbia Univ	22842	421891	18.47
13	Cornell Univ	31701	523878	16.53
14	Creighton Univ	1038	11730	11.30
15	Dartmouth College	4381	74598	17.03
16	Duke Univ	17976	314139	17.48
17	Emory Univ	7725	102594	13.28
18	Florida State Univ	4606	55149	11.97
19	George Washington Univ	4803	59525	12.39
20	Georgetown Univ	5564	73842	13.27
21	Georgia Inst Tech	3680	36859	10.02
22	Harvard Univ	56533	1407630	24.90
23	Howard Univ	2206	23269	10.55
24	Indiana Univ	14384	195702	13.61
25	Iowa State Univ	9730	97918	10.06
26	Johns Hopkins Univ	26978	528247	19.58
27	Mass Inst Tech (MIT)	25892	548954	21.20
28	Michigan State Univ	13792	183423	13.30
29	New York Univ (NYU)	15535	256632	16.52
30	Northwestern Univ	15641	216349	13.83
31	Ohio State Univ	16827	176994	10.52
32	Oregon State Univ	7964	86565	10.87
33	Penn State Univ	16193	186404	11.51
34	Princeton Univ	10812	222066	20.54
35	Purdue Univ	15825	190382	12.03
36	Rice Univ	3571	46727	13.08
37	Rockefeller Univ	7911	264924	33.49
38	Rutgers State Univ	9950	114090	11.47
39	St Louis Univ	3878	46940	12.10
40	Stanford Univ	29971	671340	22.40
41	Suny Albany	3796	52647	13.87
42	Suny Buffalo	12632	160857	12.73
43	Suny Stony Brook	14472	223492	15.44
44	Syracuse Univ	3294	35050	10.64
45	Temple Univ	6956	95983	13.80
46	Tufts Univ	8666	149863	17.29
47	Tulane Univ	6049	85964	14.21
48	Univ Alabama	11367	163556	14.39
49	Univ Alaska	1734	18642	10.75
50	Univ Arizona	15041	196467	13.06
51	Univ Calif Berkeley	31490	530839	16.86
52	Univ Calif Davis	21987	255663	11.63
53	Univ Calif Irvine	10475	167963	16.03
54	Univ Calif Los Angeles	40143	649213	16.17
55	Univ Calif Riverside	6468	84569	13.07
56	Univ Calif San Diego	24382	470551	19.30
57	Univ Calif San Francisco	27640	605267	21.50
58	Univ Calif Santa Barbara	7084	115565	16.31

Table 1 continued

59	Univ Calif Santa Cruz	2943	56775	19.29
60	Univ Chicago	19802	379126	19.14
61	Univ Cincinnati	9625	105402	10.95
62	Univ Colorado	20312	361920	17.82
63	Univ Connecticut	9812	136007	13.86
64	Univ Delaware	4550	46552	10.23
65	Univ Georgia	10674	130665	12.24
66	Univ Hawaii	7159	89242	12.47
67	Univ Houston	4776	53745	11.25
68	Univ Illinois	35323	446527	12.64
69	Univ Iowa	16196	211133	13.04
70	Univ Kansas	8892	105422	11.86
71	Univ Maryland	19460	230192	11.83
72	Univ Massachusetts	11186	134872	12.06
73	Univ Miami	9574	127888	13.36
74	Univ Michigan	26709	354920	13.29
75	Univ Minnesota	31565	440192	13.95
76	Univ New Hampshire	1832	20485	11.18
77	Univ New Mexico	5660	62551	11.05
78	Univ North Carolina	16605	231423	13.94
79	Univ Notre Dame	3528	39820	11.29
80	Univ Oklahoma	6047	61311	10.14
81	Univ Oregon	6856	117457	17.13
82	Univ Pennsylvania	27661	475067	17.17
83	Univ Pittsburgh	15505	209005	13.48
84	Univ Rhode Island	3482	42536	12.22
85	Univ Rochester	14309	215222	15.04
86	Univ South Alabama	1381	14802	10.72
87	Univ Southern Calif	16548	225997	13.66
88	Univ Tennessee	11206	127757	11.40
89	Univ Texas	54012	830471	15.38
90	Univ Utah	11941	157815	13.22
91	Univ Vermont	4227	47395	11.21
92	Univ Virginia	11928	186561	15.64
93	Univ Washington	29446	568742	19.31
94	Univ Wisconsin	34318	530677	15.46
95	Vanderbilt Univ	11044	200373	18.14
96	Virginia Commonwealth Univ	6045	67347	11.14
97	Washington Univ	17953	381781	21.27
98	Wayne State Univ	8420	102540	12.18
99	Yale Univ	26381	558748	21.18
100	Yeshiva Univ	7869	139540	17.73

Table 2
Citation Impact: 1981 - 1988

Record#	NAME	ARTICLES	CITATIONS	MEAN
1	Baylor Univ	6993	75588	10.81
2	Boston Univ	5766	58567	10.16
3	Brandeis Univ	1839	24355	13.24
4	Brigham Young Univ	1052	8441	8.02
5	Brown Univ	4296	40059	9.32
6	Calif Inst Tech (Caltech)	8536	131923	15.45
7	Carnegie Mellon Univ	2497	20107	8.05
8	Case Western Reserve	6471	57943	8.95
9	City Univ New York (CUNY)	7279	60503	8.31
10	College William and Mary	558	4529	8.12
11	Colorado State Univ	4003	28013	7.00
12	Columbia Univ	11781	136067	11.55
13	Cornell Univ	16910	174873	10.34
14	Creighton Univ	571	4782	8.37
15	Dartmouth College	2380	28402	11.93
16	Duke Univ	9891	109954	11.12
17	Emory Univ	4317	38916	9.01
18	Florida State Univ	2175	18422	8.47
19	George Washington Univ	2676	22544	8.42
20	Georgetown Univ	3000	26134	8.71
21	Georgia Inst Tech	1919	13086	6.82
22	Harvard Univ	30228	491663	16.26
23	Howard Univ	941	6617	7.03
24	Indiana Univ	7396	67852	9.17
25	Iowa State Univ	4900	31539	6.44
26	Johns Hopkins Univ	14325	178437	12.45
27	Mass Inst Tech (MIT)	13486	195921	14.53
28	Michigan State Univ	6669	59700	8.95
29	New York Univ (NYU)	7694	88943	11.56
30	Northwestern Univ	8064	71841	8.91
31	Ohio State Univ	8630	59178	6.86
32	Oregon State Univ	4087	26790	6.55
33	Penn State Univ	8257	67238	8.14
34	Princeton Univ	5199	68802	13.23
35	Purdue Univ	7878	61892	7.86
36	Rice Univ	1683	15134	8.99
37	Rockefeller Univ	4058	84718	20.88
38	Rutgers State Univ	4876	34094	6.99
39	St Louis Univ	2004	17396	8.68
40	Stanford Univ	15834	225929	14.27
41	Suny Albany	1676	15744	9.39
42	Suny Buffalo	5119	40417	7.90
43	Suny Stony Brook	6698	70367	10.51
44	Syracuse Univ	1606	12941	8.06
45	Temple Univ	3110	26258	8.44
46	Tufts Univ	4850	60747	12.53
47	Tulane Univ	2850	23996	8.56
48	Univ Alabama	6436	65206	10.13
49	Univ Alaska	903	6205	6.87
50	Univ Arizona	8550	75367	8.81
51	Univ Calif Berkeley	16347	187872	11.49
52	Univ Calif Davis	11024	83587	7.58
53	Univ Calif Irvine	5641	56419	10.00
54	Univ Calif Los Angeles	20271	217515	10.73
55	Univ Calif Riverside	3200	29030	9.07
56	Univ Calif San Diego	12675	159907	12.62
57	Univ Calif San Francisco	14910	215487	14.45
58	Univ Calif Santa Barbara	4022	49473	12.30

Table 2 continued

59	Univ Calif Santa Cruz	1541	19353	12.56
60	Univ Chicago	9710	122860	12.65
61	Univ Cincinnati	5282	41688	7.89
62	Univ Colorado	10587	123560	11.67
63	Univ Connecticut	4916	44749	9.10
64	Univ Delaware	2592	18517	7.14
65	Univ Georgia	5137	33864	6.59
66	Univ Hawaii	3355	28730	8.56
67	Univ Houston	2704	24393	9.02
68	Univ Illinois	18096	149643	8.27
69	Univ Iowa	8469	73340	8.66
70	Univ Kansas	4135	31903	7.72
71	Univ Maryland	10730	91124	8.49
72	Univ Massachusetts	6307	57508	9.12
73	Univ Miami	4644	40197	8.66
74	Univ Michigan	14494	133444	9.21
75	Univ Minnesota	16278	158981	9.77
76	Univ New Hampshire	954	7459	7.82
77	Univ New Mexico	3079	23008	7.47
78	Univ North Carolina	9205	90821	9.87
79	Univ Notre Dame	1860	13950	7.50
80	Univ Oklahoma	3145	23242	7.39
81	Univ Oregon	2356	28125	11.94
82	Univ Pennsylvania	14108	153468	10.88
83	Univ Pittsburgh	8264	74572	9.02
84	Univ Rhode Island	1718	13178	7.67
85	Univ Rochester	7109	68519	9.64
86	Univ South Alabama	964	8453	8.77
87	Univ Southern Calif	8393	76612	9.13
88	Univ Tennessee	5747	42505	7.40
89	Univ Texas	30272	309240	10.22
90	Univ Utah	6650	61225	9.21
91	Univ Vermont	2064	17103	8.29
92	Univ Virginia	6414	64925	10.12
93	Univ Washington	15770	202848	12.86
94	Univ Wisconsin	16831	155350	9.23
95	Vanderbilt Univ	6044	70514	11.67
96	Virginia Commonwealth Univ	4003	34616	8.65
97	Washington Univ	9384	131454	14.01
98	Wayne State Univ	4084	32485	7.95
99	Yale Univ	13516	194410	14.38
100	Yeshiva Univ	4522	58201	12.88

Table 3

Change in Rank from 1973-1988 Means to 1981-1988 Means

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INSTITUTION	73-88	RANK1	81-88	RANK2	CHANGE
Univ South Alabama	10.72	90	8.77	58	32
Univ Houston	11.25	82	9.02	51	31
Univ Massachusetts	12.06	71	9.12	47	24
Virginia Commonwealth Univ	11.14	85	8.65	63	22
Brigham Young Univ	10.26	96	8.02	78	18
College William and Mary	10.60	93	8.12	75	18
Syracuse Univ	10.64	91	8.06	76	15
Univ Utah	13.22	57	9.21	43	14
Univ Vermont	11.21	83	8.29	72	11
St Louis Univ	12.10	70	8.68	60	10
Univ Calif Riverside	13.07	59	9.07	49	10
Univ Calif Santa Barbara	16.31	28	12.30	18	10
Univ Michigan	13.29	54	9.21	44	10
Creighton Univ	11.30	80	8.37	70	10
Brown Univ	13.55	50	9.32	41	9
Univ Maryland	11.83	75	8.49	66	9
Univ Oklahoma	10.14	98	7.39	90	8
Yeshiva Univ	17.73	19	12.88	11	8
Florida State Univ	11.97	73	8.47	67	6
Univ Delaware	10.23	97	7.14	91	6
Univ Cincinnati	10.95	87	7.89	81	6
Rice Univ	13.08	58	8.99	53	5
Suny Stony Brook	15.44	35	10.51	30	5
Tufts Univ	17.29	21	12.53	16	5
Univ North Carolina	13.94	42	9.87	37	5
Dartmouth College	17.03	24	11.93	20	4
Mass Inst Tech (MIT)	21.20	8	14.53	4	4
Univ Alabama	14.39	38	10.13	34	4
New York Univ (NYU)	16.52	27	11.56	23	4
Univ Oregon	17.13	23	11.94	19	4
Univ Texas	15.38	36	10.22	32	4
Emory Univ	13.28	55	9.01	52	3
Indiana Univ	13.61	48	9.17	45	3
Penn State Univ	11.51	77	8.14	74	3
Georgia Inst Tech	10.02	100	6.82	97	3
Univ Arizona	13.06	60	8.81	57	3
Univ Minnesota	13.95	41	9.77	38	3
Yale Univ	21.18	9	14.38	6	3
Baylor Univ	15.91	31	10.81	28	3
Suny Albany	13.87	43	9.39	40	3
Univ Chicago	19.14	15	12.65	13	2
Howard Univ	10.55	94	7.03	92	2
Univ New Hampshire	11.18	84	7.82	83	1
Univ Pittsburgh	13.48	51	9.02	50	1
Calif Inst Tech (Caltech)	22.32	4	15.45	3	1
Univ Calif San Francisco	21.50	6	14.45	5	1
Univ Southern Calif	13.66	47	9.13	46	1
Princeton Univ	20.54	10	13.23	10	0
Univ Iowa	13.04	61	8.66	61	0
Rockefeller Univ	33.49	1	20.88	1	0
Harvard Univ	24.90	2	16.26	2	0

Table 3 continued

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INSTITUTION	73-88	RANK1	81-88	RANK2	CHANGE
Univ Washington	19.31	12	12.86	12	0
Univ Calif Berkeley	16.86	25	11.49	25	0
Univ Calif Los Angeles	16.17	29	10.73	29	0
Univ Hawaii	12.47	65	8.56	65	0
Boston Univ	15.53	33	10.16	33	0
Ohio State Univ	10.52	95	6.86	96	-1
Colorado State Univ	10.62	92	7.00	93	-1
Washington Univ	21.27	7	14.01	8	-1
Univ Calif Santa Cruz	19.29	14	12.56	15	-1
Iowa State Univ	10.06	99	6.44	100	-1
Univ Calif San Diego	19.30	13	12.62	14	-1
Univ Rochester	15.04	37	9.64	39	-2
Michigan State Univ	13.30	53	8.95	55	-2
Univ New Mexico	11.05	86	7.47	88	-2
Univ Colorado	17.82	18	11.67	21	-3
George Washington Univ	12.39	66	8.42	69	-3
Univ Virginia	15.64	32	10.12	35	-3
Georgetown Univ	13.27	56	8.71	59	-3
Brandeis Univ	21.92	5	13.24	9	-4
Stanford Univ	22.40	3	14.27	7	-4
Univ Connecticut	13.86	44	9.10	48	-4
Cornell Univ	16.53	26	10.34	31	-5
Vanderbilt Univ	18.14	17	11.67	22	-5
Case Western Reserve	13.61	49	8.95	54	-5
Univ Pennsylvania	17.17	22	10.88	27	-5
Johns Hopkins Univ	19.58	11	12.45	17	-6
Univ Calif Irvine	16.03	30	10.00	36	-6
Duke Univ	17.48	20	11.12	26	-6
Univ Notre Dame	11.29	81	7.50	87	-6
Univ Alaska	10.75	89	6.87	95	-6
Columbia Univ	18.47	16	11.55	24	-8
Univ Wisconsin	15.46	34	9.23	42	-8
City Univ New York (CUNY)	12.72	63	8.31	71	-8
Univ Illinois	12.64	64	8.27	73	-9
Purdue Univ	12.03	72	7.86	82	-10
Univ Miami	13.36	52	8.66	62	-10
Univ Tennessee	11.40	79	7.40	89	-10
Univ Kansas	11.86	74	7.72	84	-10
Wayne State Univ	12.18	69	7.95	79	-10
Univ Calif Davis	11.63	76	7.58	86	-10
Northwestern Univ	13.83	45	8.91	56	-11
Oregon State Univ	10.87	88	6.55	99	-11
Rutgers State Univ	11.47	78	6.99	94	-16
Univ Rhode Island	12.22	68	7.67	85	-17
Suny Buffalo	12.73	62	7.90	80	-18
Temple Univ	13.80	46	8.44	68	-22
Tulane Univ	14.21	39	8.56	64	-25
Univ Georgia	12.24	67	6.59	98	-31
Carnegie Mellon Univ	14.02	40	8.05	77	-37

Table 4

Percent Change from 1973-1988 Means to 1981-1988 Means

Record#	NAME	MEAN7388	MEAN8188	PERCENT
1	Univ South Alabama	10.72	8.77	18.19
2	Univ Houston	11.25	9.02	19.82
3	Brigham Young Univ	10.26	8.02	21.83
4	Virginia Commonwealth Univ	11.14	8.65	22.35
5	College William and Mary	10.60	8.12	23.40
6	Syracuse Univ	10.64	8.06	24.25
7	Univ Massachusetts	12.06	9.12	24.38
8	Univ Calif Santa Barbara	16.31	12.30	24.59
9	Creighton Univ	11.30	8.37	25.93
10	Univ Vermont	11.21	8.29	26.05
11	Univ Oklahoma	10.14	7.39	27.12
12	Yeshiva Univ	17.73	12.88	27.35
13	Tufts Univ	17.29	12.53	27.53
14	Univ Cincinnati	10.95	7.89	27.95
15	Univ Maryland	11.83	8.49	28.23
16	St Louis Univ	12.10	8.68	28.26
17	Univ North Carolina	13.94	9.87	29.20
18	Florida State Univ	11.97	8.47	29.24
19	Penn State Univ	11.51	8.14	29.28
20	Univ Alabama	14.39	10.13	29.60
21	Dartmouth College	17.03	11.93	29.95
22	Univ Minnesota	13.95	9.77	29.96
23	New York Univ (NYU)	16.52	11.56	30.02
24	Univ New Hampshire	11.18	7.82	30.05
25	Univ Delaware	10.23	7.14	30.21
26	Univ Oregon	17.13	11.94	30.30
27	Univ Utah	13.22	9.21	30.33
28	Univ Calif Riverside	13.07	9.07	30.60
29	Univ Michigan	13.29	9.21	30.70
30	Calif Inst Tech (Caltech)	22.32	15.45	30.78
31	Brown Univ	13.55	9.32	31.22
32	Rice Univ	13.08	8.99	31.27
33	Univ Hawaii	12.47	8.56	31.36
34	Mass Inst Tech (MIT)	21.20	14.53	31.46
35	Univ Calif Berkeley	16.86	11.49	31.85
36	Suny Stony Brook	15.44	10.51	31.93
37	Georgia Inst Tech	10.02	6.82	31.94
38	George Washington Univ	12.39	8.42	32.04
39	Baylor Univ	15.91	10.81	32.06
40	Yale Univ	21.18	14.38	32.11
41	Emory Univ	13.28	9.01	32.15
42	Suny Albany	13.87	9.39	32.30
43	Univ New Mexico	11.05	7.47	32.40
44	Univ Arizona	13.06	8.81	32.54
45	Indiana Univ	13.61	9.17	32.62
46	Michigan State Univ	13.30	8.95	32.71
47	Univ Calif San Francisco	21.50	14.45	32.79
48	Univ Pittsburgh	13.48	9.02	33.09
49	Univ Southern Calif	13.66	9.13	33.16
50	Howard Univ	10.55	7.03	33.36
51	Univ Washington	19.31	12.86	33.40
52	Univ Texas	15.38	10.22	33.55
53	Univ Notre Dame	11.29	7.50	33.57
54	Univ Iowa	13.04	8.66	33.59
55	Univ Calif Los Angeles	16.17	10.73	33.64
56	Univ Chicago	19.14	12.65	33.91
57	Colorado State Univ	10.62	7.00	34.09
58	Washington Univ	21.27	14.01	34.13

Table 4 continued

59	Case Western Reserve	13.61	8.95	34.24
60	Univ Connecticut	13.86	9.10	34.34
61	Georgetown Univ	13.27	8.71	34.36
62	Univ Colorado	17.82	11.67	34.51
63	Univ Illinois	12.64	8.27	34.57
64	Boston Univ	15.53	10.16	34.58
65	Univ Calif San Diego	19.30	12.62	34.61
66	Purdue Univ	12.03	7.86	34.66
67	City Univ New York (CUNY)	12.72	8.31	34.67
68	Harvard Univ	24.90	16.26	34.70
69	Wayne State Univ	12.18	7.95	34.73
70	Ohio State Univ	10.52	6.86	34.79
71	Univ Calif Davis	11.63	7.58	34.82
72	Univ Calif Santa Cruz	19.29	12.56	34.89
73	Univ Kansas	11.86	7.72	34.91
74	Univ Tennessee	11.40	7.40	35.09
75	Univ Miami	13.36	8.66	35.18
76	Univ Virginia	15.64	10.12	35.29
77	Northwestern Univ	13.83	8.91	35.57
78	Princeton Univ	20.54	13.23	35.59
79	Vanderbilt Univ	18.14	11.67	35.67
80	Univ Rochester	15.04	9.64	35.90
81	Iowa State Univ	10.06	6.44	35.98
82	Univ Alaska	10.75	6.87	36.09
83	Stanford Univ	22.40	14.27	36.29
84	Duke Univ	17.48	11.12	36.38
85	Johns Hopkins Univ	19.58	12.45	36.41
86	Univ Pennsylvania	17.17	10.88	36.63
87	Univ Rhode Island	12.22	7.67	37.23
88	Cornell Univ	16.53	10.34	37.45
89	Columbia Univ	18.47	11.55	37.47
90	Univ Calif Irvine	16.03	10.00	37.62
91	Rockefeller Univ	33.49	20.88	37.65
92	Suny Buffalo	12.73	7.90	37.94
93	Temple Univ	13.80	8.44	38.84
94	Rutgers State Univ	11.47	6.99	39.06
95	Brandeis Univ	21.92	13.24	39.60
96	Oregon State Univ	10.87	6.55	39.74
97	Tulane Univ	14.21	8.56	39.76
98	Univ Wisconsin	15.46	9.23	40.30
99	Carnegie Mellon Univ	14.02	8.05	42.58
100	Univ Georgia	12.24	6.59	46.16

b. Bibliometric Profiles for Selected Institutions

The next task was to select some actual institutions of interest to OTA and then examine what changes have occurred in those institutions and how they might be accounted for. The list of selected institutions is shown in Table 5. One institution selected by OTA was not among the set of 100, namely Woods Hole. In addition, OTA selected the University of Texas at Austin and the University of Massachusetts at Amherst, whereas the Univ Texas and Univ Massachusetts on the previous tables cover all institutions within those state systems. To select a specific institution within these state systems, a selection by city and institution was carried out.

The publication and citation records for each of the 19 institutions in Table 5 was extracted on a separate file and a statistical program was then run to obtain citation impact time series. A citation impact calculation requires specifying four time points: a beginning and ending cited item period, and a beginning and ending citing item time period. In other words, we must define what items are eligible for receiving citations and what items are eligible for giving them. Since we want to construct a time series of impacts which are comparable over time, we can define these four time points, beginning in 1973, and then slide or increment each of them by one year until we reach the last year of our data, namely 1988. If we define, for example, the length of the period to be eight years, and the cited item period to be coincident with the citing item period, then we obtain nine successive overlapping time windows which can be plotted as a time series.

For each of the eight year time windows three numbers were calculated: the total number of cited publications, the total number of citations they received, and the ratio of citations to publications (mean citations per cited item). For example, in the first window from 1973 through 1980, we count the number of cited papers published from 1973 through 1980 by the institution in question and the number of times those papers were cited by papers published in the same period. The ratio of these quantities is the mean citations per cited item for that time window.

As a further normalization we divide each of the impacts by the overall average for all U.S. papers for the specific time window, i.e. 1973-1980. The result we call a relative impact. Thus, a relative impact score of one signifies that the institution's average is identical to the average for all U.S. papers in the window. A score greater than one, signifies an impact above the U.S. average, and a score below one, an impact below the U.S. average.

The time series plots of relative impact for all 19 selected institutions are given in Figures 1 through 19. All institutions are plotted using the same nine eight-year windows and the same range of relative impact (from .7 to 1.5 times the average for

all U.S. papers) for comparison purposes. In order to attempt to explain the trends shown in these graphs in terms of the fields of science involved, listings of the most cited papers were obtained for each institution, covering items cited 100 or more times, down to a maximum of 100 items. Each of the 19 institutions will now be discussed with reference to the citation impact plot and most cited paper listings:

1. Carnegie Mellon University

This institution shows a decline in relative impact, beginning in the late 1970s. An analysis of the 78 papers cited 100 times or more shows that 15 percent of these papers are in the period 1981 through 1988. While 23 percent of the 1973 through 1980 papers were in the discipline of physics, only 8 percent are from physics in the later period. Chemistry, biomedicine and computer science continue from earlier to later periods at comparable levels. Hence, the cause of the decline in citation impact might be attributable to a weakening in the physics program.

2. Duke University

This institution shows a moderate decline in citation impact across the 16 year period. Analysis of the top 100 cited papers shows a predominance of biomedical research (biochemistry, cardiology, pharmacology). The proportion of papers in the period 1981 through 1988 is 17 percent. There does not appear to be a shift in research topics that can account for the moderate decline in impact.

3. Johns Hopkins University

This institution shows a moderate decline in citation impact, similar to the previous institution. The proportion of papers from 1981-1988 is only 12 percent. The dominant discipline is biomedicine, with particular strength in neuroscience. No disciplinary shift is apparent which might account for the decline in impact.

4. Massachusetts Institute of Technology

This institution shows a modest gain in citation impact. Twenty-nine percent (29%) of its most cited papers are from the 1981-1988 period. Biomedicine has become stronger going from earlier to later periods, while chemistry and geoscience have become weaker, physics remaining about the same. Thus the increase in citation impact may have been made at the expense of other fields.

5. Princeton University

This institution shows a moderate decline in the late 1970s, followed by a slight recovery. Twenty-eight percent (28%) of the most cited papers are from 1981-1988, similar to the previous

case. The fields have shifted from an even balance between physics and biomedicine to an almost exclusive concentration on physics. Chemistry and geoscience are represented in the earlier but not later period. There appear to be intentional shifts in field emphasis, which may or may not increase the institution's citation impact in the future. The deemphasis of biomedicine may have caused some decline.

6. Stanford University

This institution shows an increase to the early 1980s, followed by a moderate decrease. Twenty-three percent (23%) of the most cited articles are from 1981-1988. There is an emphasis on biomedical research. Physics and chemistry are strong in the earlier period, but weaker in the later period. In this case the moderate decline may be due to a weakening of the physical sciences.

7. Tulane University

This institution experienced a marked decline in citation impact in the 1970s followed by a slower decline in the 1980s. Twelve percent (12%) of its 91 papers cited 100 times or more are dated 1981-1988. The earlier work is dominated by biomedical work, especially endocrinology. The later period shows an emergence of physics but biomedicine is still dominant. The reason for the decline is not clear.

8. University of California Davis

This institution has a flat citation impact record at a fairly low level. This low impact seems to be due to a large number of low cited papers, rather than a lack of highly cited ones. The proportion of highly cited papers published 1981-1988 is 14 percent. The emphasis is on biomedicine, with special strength in plant science and ecology. These topics continue from the earlier to later periods. Physics, however, which appears in the early period (5%) does not appear later.

9. University of California San Diego

This institution also has a fairly constant citation impact, but at a higher level than the previous institution. The proportion of 1981-1988 highly cited papers is 17 percent. The emphasis is again biomedical. Physics and geoscience are present in the earlier period but absent in the later one.

10. University of California Santa Barbara

This institution has a very marked and consistent increase in citation impact. It also has a very large number of 1981-1988 papers in its highly cited set, namely 43 percent. Even more remarkable is the spread of these papers over various disciplines, with the emphasis on physics. Of the recent highly cited papers, 81 percent are in physics. Other areas are also repre-

sented, including biomedicine, ecology, geoscience, and chemistry. Of the institutions examined thus far, it has the best balance among disciplines as represented in the most cited papers.

11. University of Georgia

This institution shows a declining and rather low level of citation impact, after a modest increase in the late 1970s. Thus far it has the lowest percentage of its most cited papers in the 1981-1988 period, namely 7 percent. There are only 60 papers cited 100 times or more. The biomedical papers are strong in plant science. Chemistry is strong in the highly cited set (20 percent) and physics and ecology are also represented.

12. University of Houston

This institution displays one of the most marked increases in citation impact of the institutions examined thus far, although it started at a very low level. Its number of papers cited over 100 times is also the smallest, namely 28. Nevertheless, 39 percent of these are from the recent period 1981-1988, which is second only to University of California Santa Barbara. Physics and more specifically high temperature superconductivity dominate the new highly cited papers, but biomedicine is also represented. In the earlier period, chemistry and biomedicine were dominant. Possibly a shift toward strengthening physics contributed to the increase in impact for this institution.

13. University of Illinois

This institution shows a small decline in citation impact. The number of recent highly cited papers is low, namely 10 percent. The older period is dominated by biomedical papers (59%) which includes a strong contingent of plant science, microbiology, and zoology. Physics and chemistry are also strong. In the recent period only biomedical and physics papers appear in equal proportions. This suggests a decline in chemistry and perhaps also biology.

14. University of Maryland

This institution shows a gradual increase in citation impact across the period. The number of highly cited papers from the 1981-1988 period is 26 percent. Physics and biomedicine dominate the early and late periods, and remain in about the same proportions. Chemistry appears in the early period, but not the late one. Areas of physics include particle, superconductivity, and chaos.

15. University of Massachusetts Amherst

This institution shows a steady increase in citation impact over the period. Twenty-four percent (24%) of the highly cited papers are from the 1981-1988 period. There is a good balance of

fields in the highly cited papers. In the early period biomedicine, with a strong component of zoology and botany, leads, but physics, with strong astrophysics, is a close second. Chemistry is also strong. In the more recent period, physics is dominant, again with astrophysics a major contributor. Biomedicine and chemistry are also represented in the recent period. This institution resembles University of California Santa Barbara in its balance of good work across various disciplines.

16. University of Michigan

This institution shows a slight dip in the late 1970s in citation impact followed by a steady recovery in the 1980s. Twenty-five percent of its most cited papers are from the 1981-1988 period. Biomedicine is the dominant field, and within it, toxicology, cardiology, psychiatry and ecology are strong. Physics and chemistry are relatively weak, but space science cuts across these fields (including geoscience) and is well represented. Going from early to late periods biomedicine holds its position and physics is strengthened, but space science loses strength.

17. University of Texas Austin

This institution moves up slightly in citation impact in the late 1970s, and then moves down slightly in the 1980s. The percent of recent highly cited papers is 22 percent, which is moderately good for this sample. This is the only institution in our sample where the field of chemistry is dominant, at least in the early period. Forty-five percent of the most cited papers are in chemistry in the early period, with a slight decline to 36% in the current period. Physics, and particularly astrophysics, is second to chemistry in the early period, and replaces chemistry in the late period as the dominant field at 45 percent. Biomedicine remains constant at about 20 percent. Ecology appears in the early but not the late period. It appears that chemistry has been traded off for physics for no net gain in citation impact.

18. University of Washington

This institution shows a gradual increase in citation impact over the period. However, only 10 percent of the most cited papers are from the period 1981-1988, which is low for an increasing impact trend. The most cited papers are dominated by biomedicine, in the early and late periods. The presence of older heavily cited medical classics, such as work on atherosclerosis, makes it difficult for less cited fields to appear among the most cited papers.

19. Woods Hole

This institution shows a general upward trend in citation impact to the mid-1980s, followed by a short downtrend in the late 1980s. Only 10 percent of the 51 papers cited 100 times or more are from the period 1981-1988. Not surprisingly, nearly all

the most cited papers from this institution are in the fields of geoscience or marine biology. Geoscience accounts for a majority (58 percent), and biological studies 30 percent. Physics, chemical and meteorology account for the remainder. The recent highly cited papers are split between geoscience and biology.

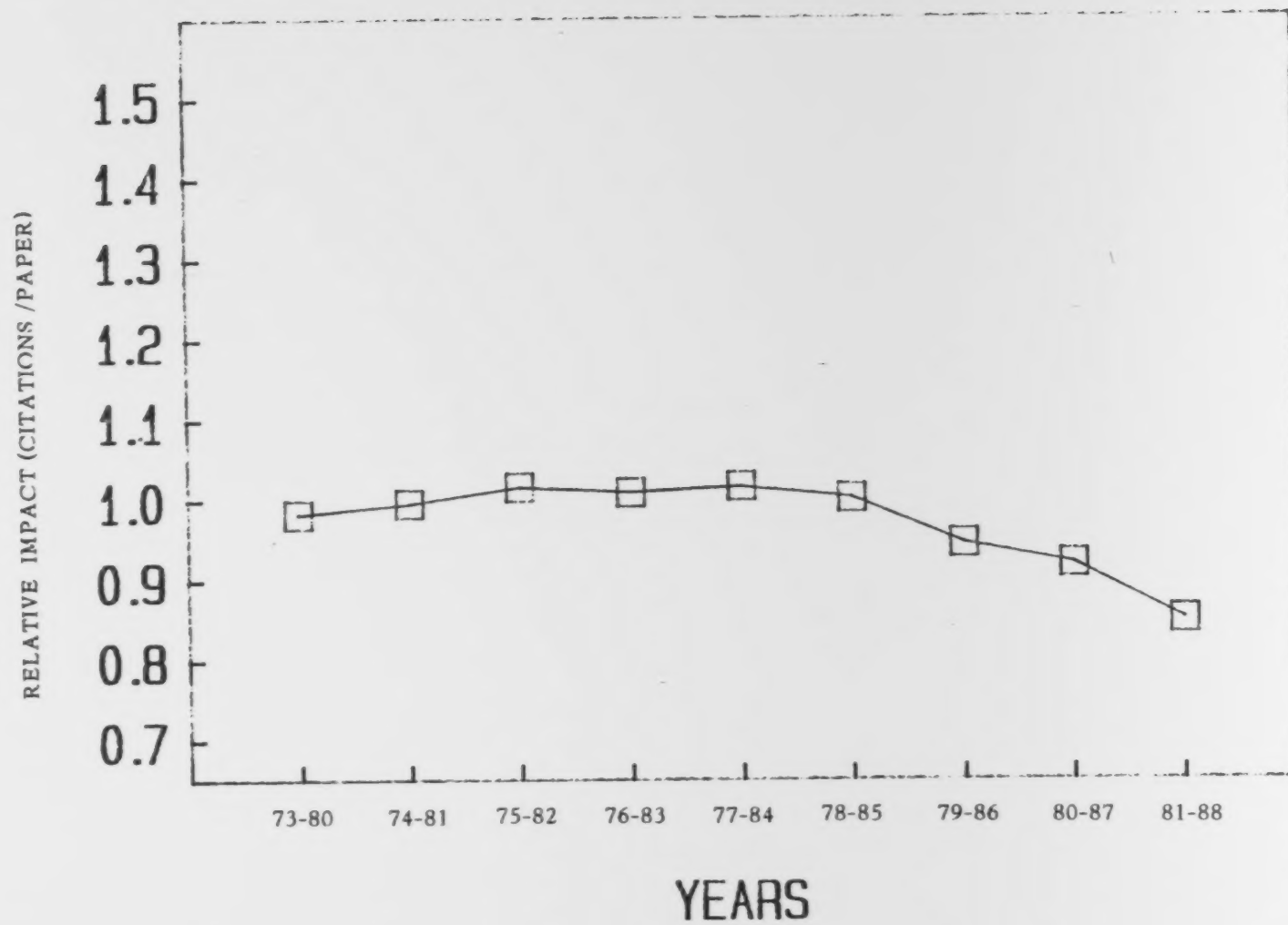
Table 5

SELECTED INSTITUTIONS

CARNEGIE MELLON UNIV
DUKE UNIV
JOHNS HOPKINS UNIV
MASS INST TECH (MIT)
PRINCETON UNIV
STANFORD UNIV
TULANE UNIV
UNIV CALIF DAVIS
UNIV CALIF SAN DIEGO
UNIV CALIF SANTA BARBARA
UNIV GEORGIA
UNIV HOUSTON
UNIV ILLINOIS
UNIV MARYLAND
UNIV MASSACHUSETTS AMHERST
UNIV MICHIGAN
UNIV TEXAS AUSTIN
UNIV WASHINGTON
WOODS HOLE

Figure 1

CARNEGIE MELLON UNIV



DUKE UNIV

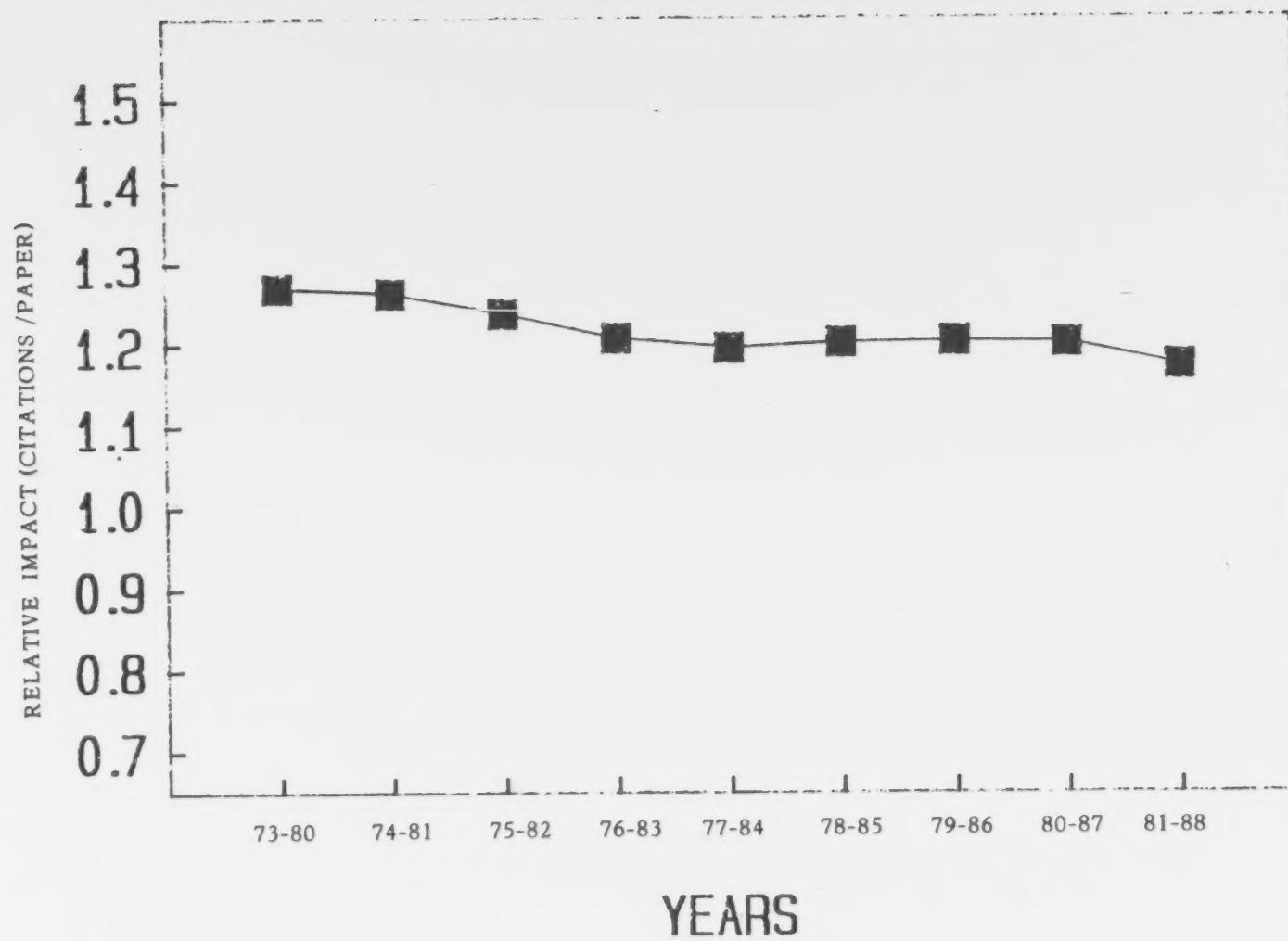


Figure 3

JOHNS HOPKINS UNIV

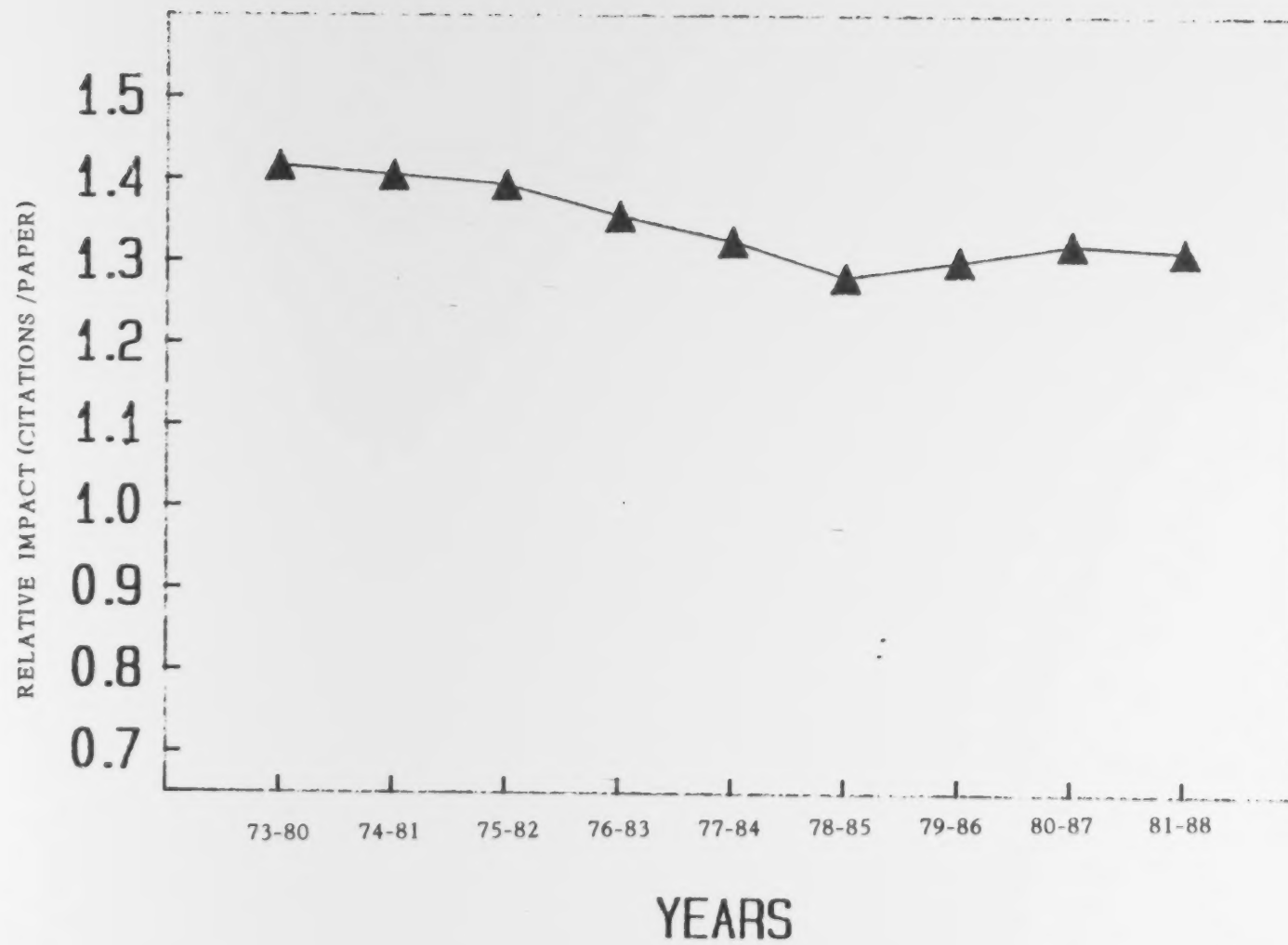


Figure 4

MASS INST TECH (MIT)

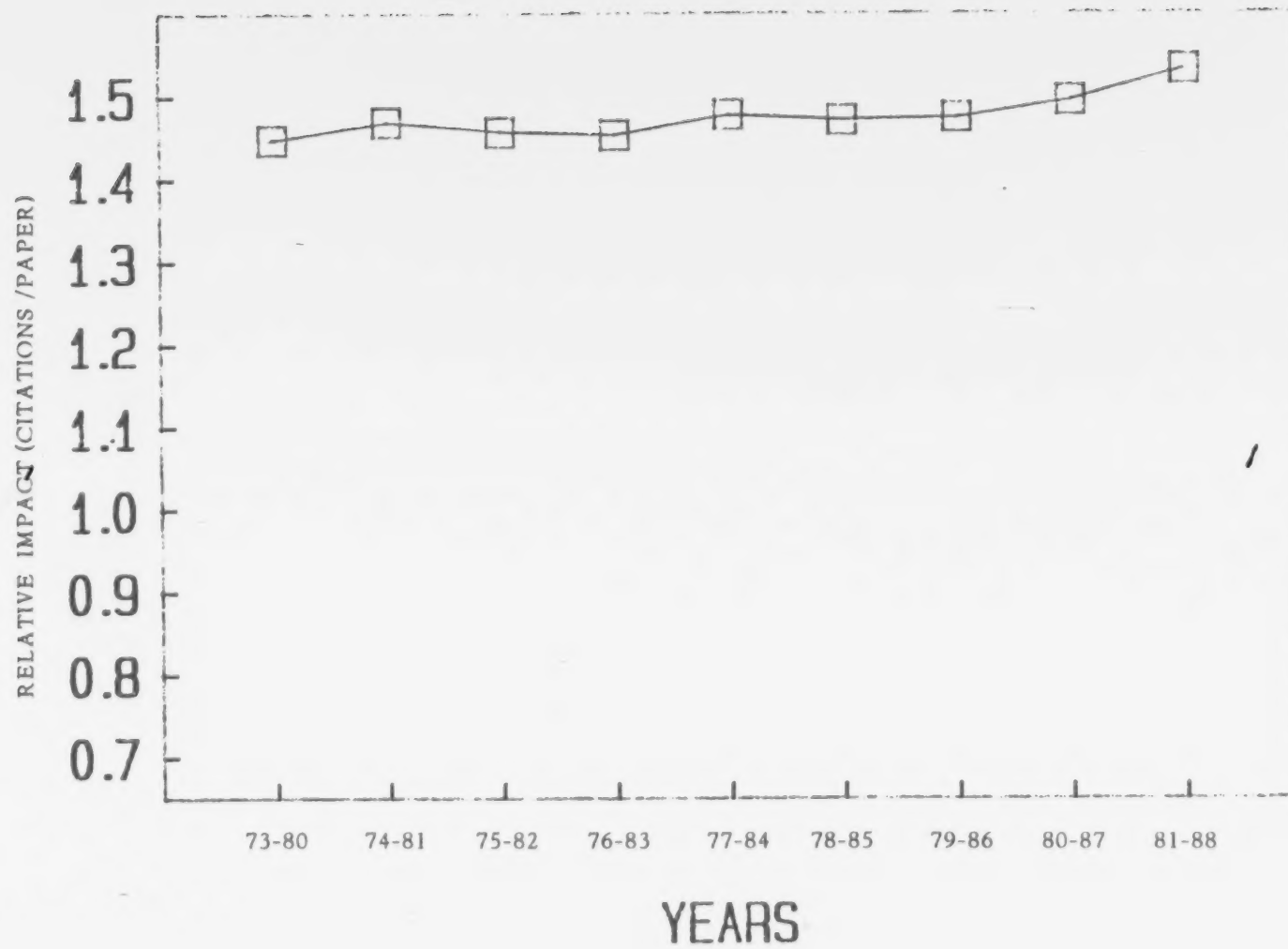


Figure 5

PRINCETON UNIV

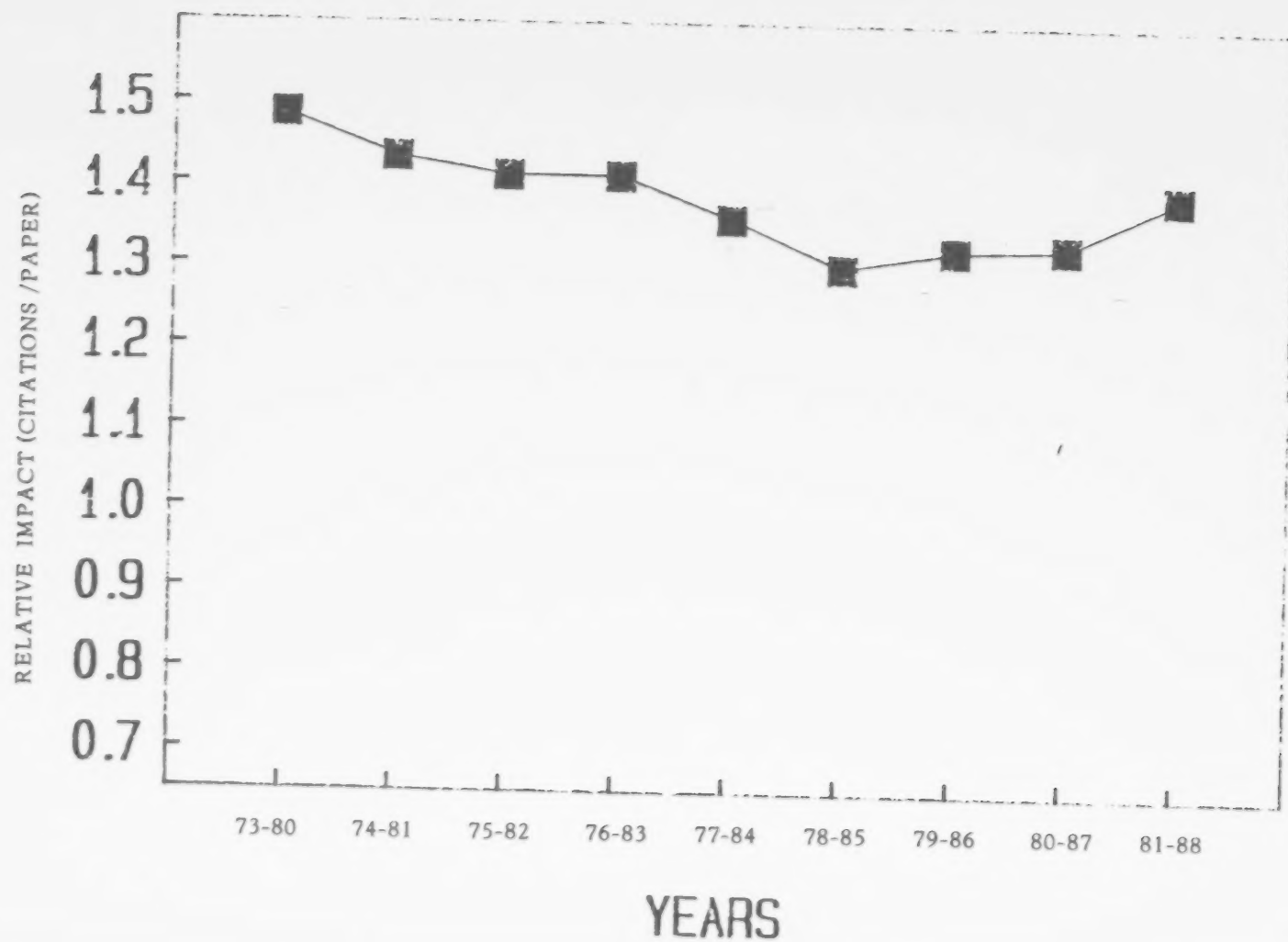


Figure 6

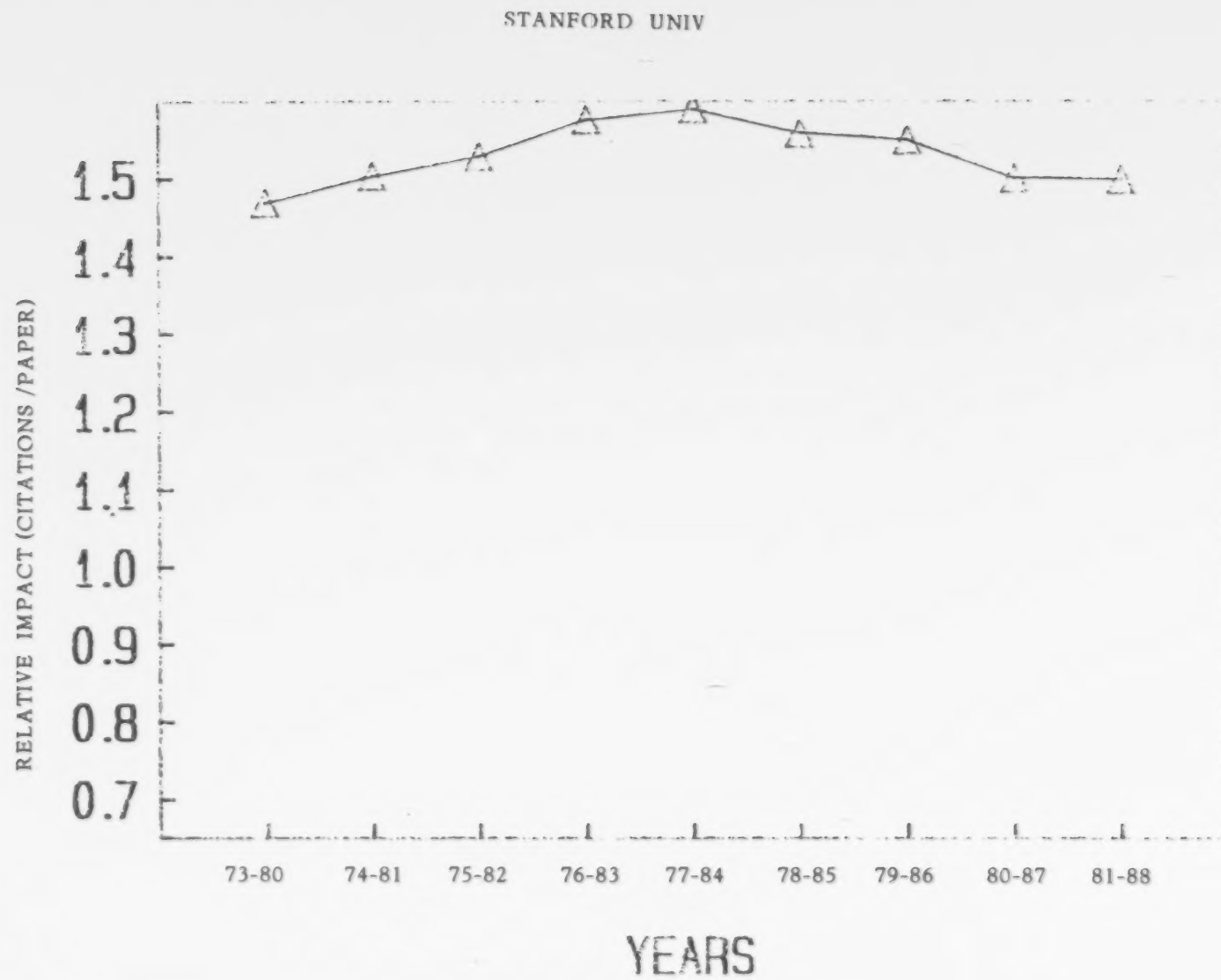


Figure 7

TULANE UNIV

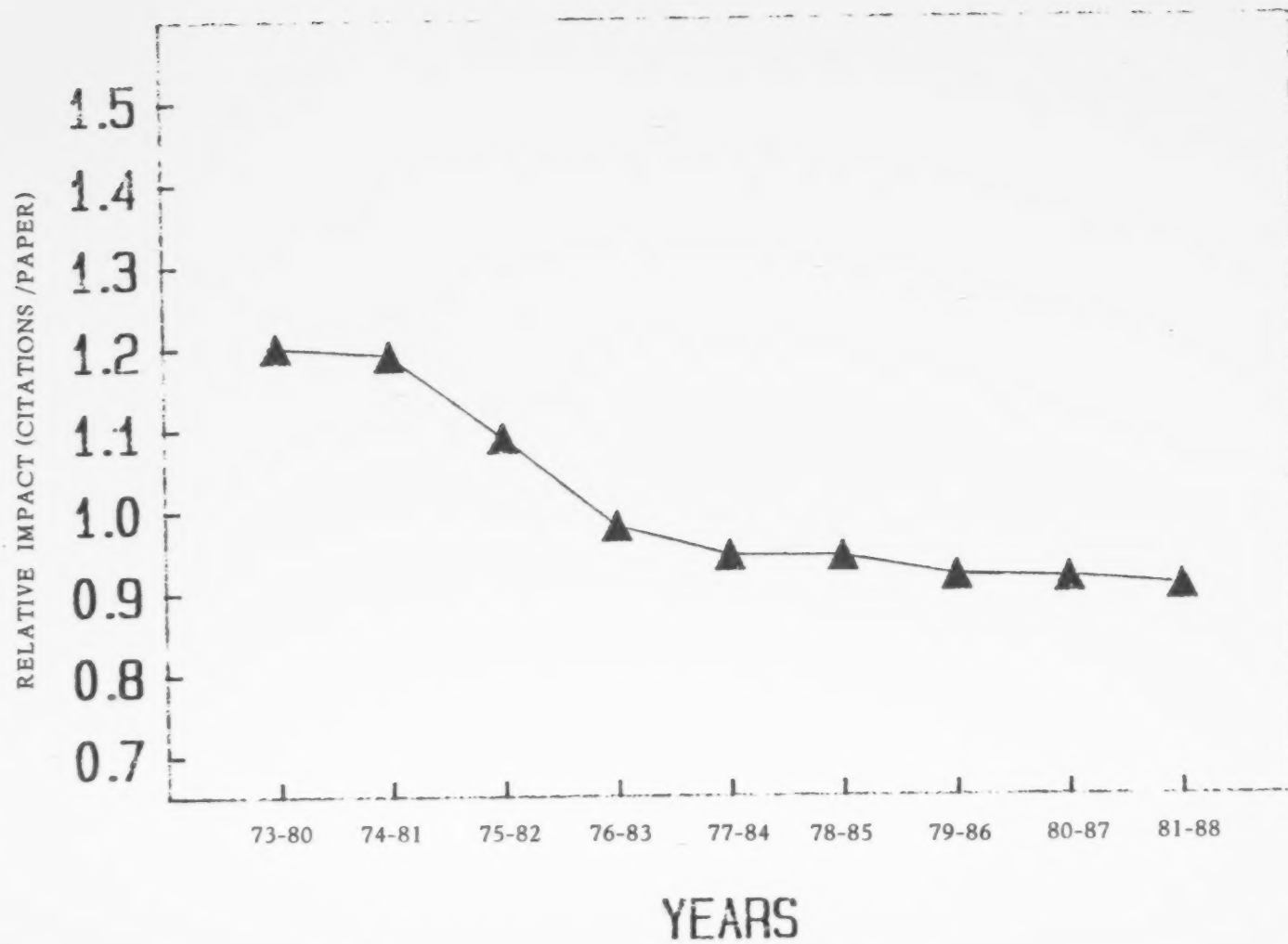


Figure 8

UNIV CALIF DAVIS

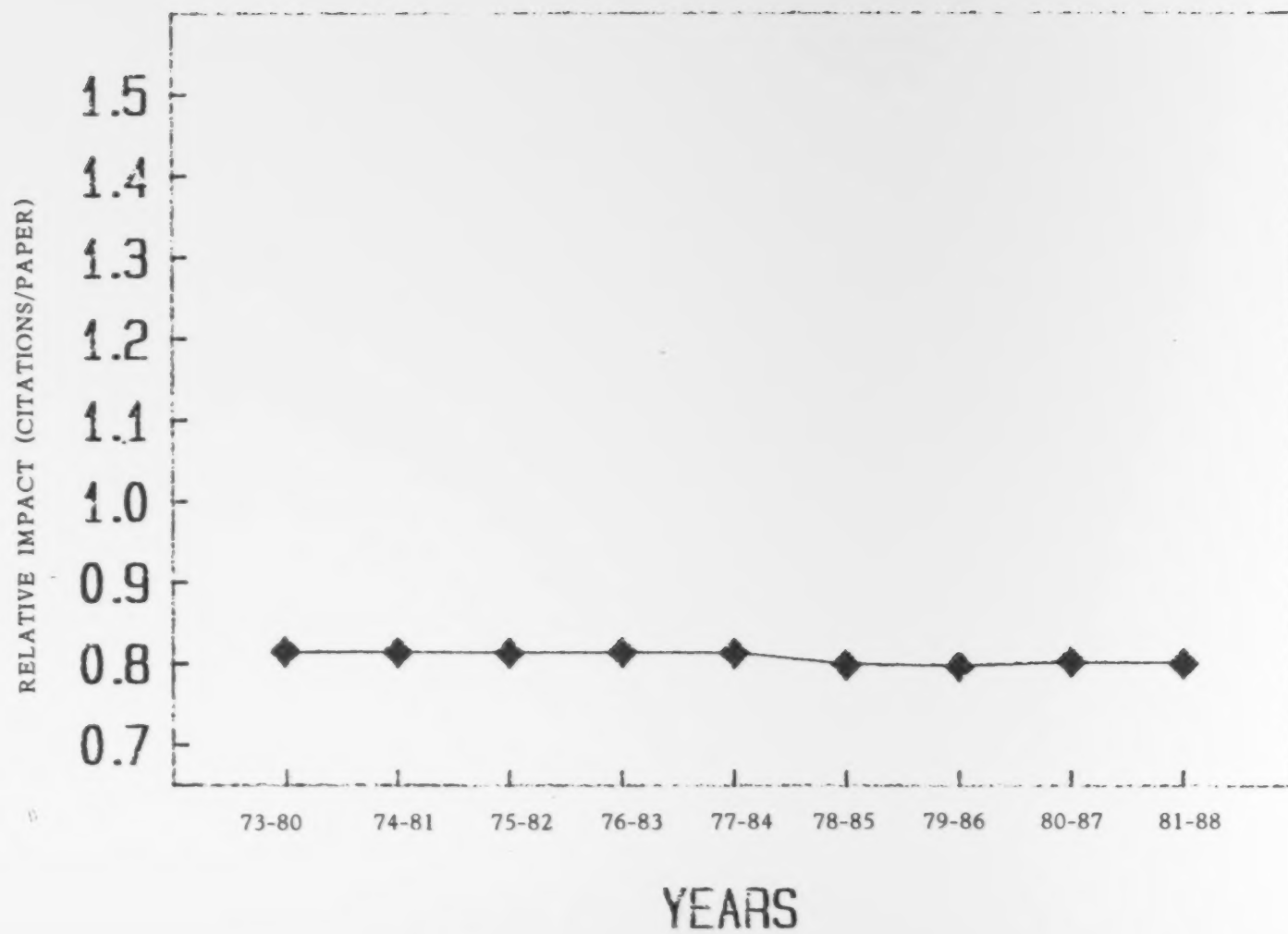


Figure 9

UNIV CALIF SAN DIEGO

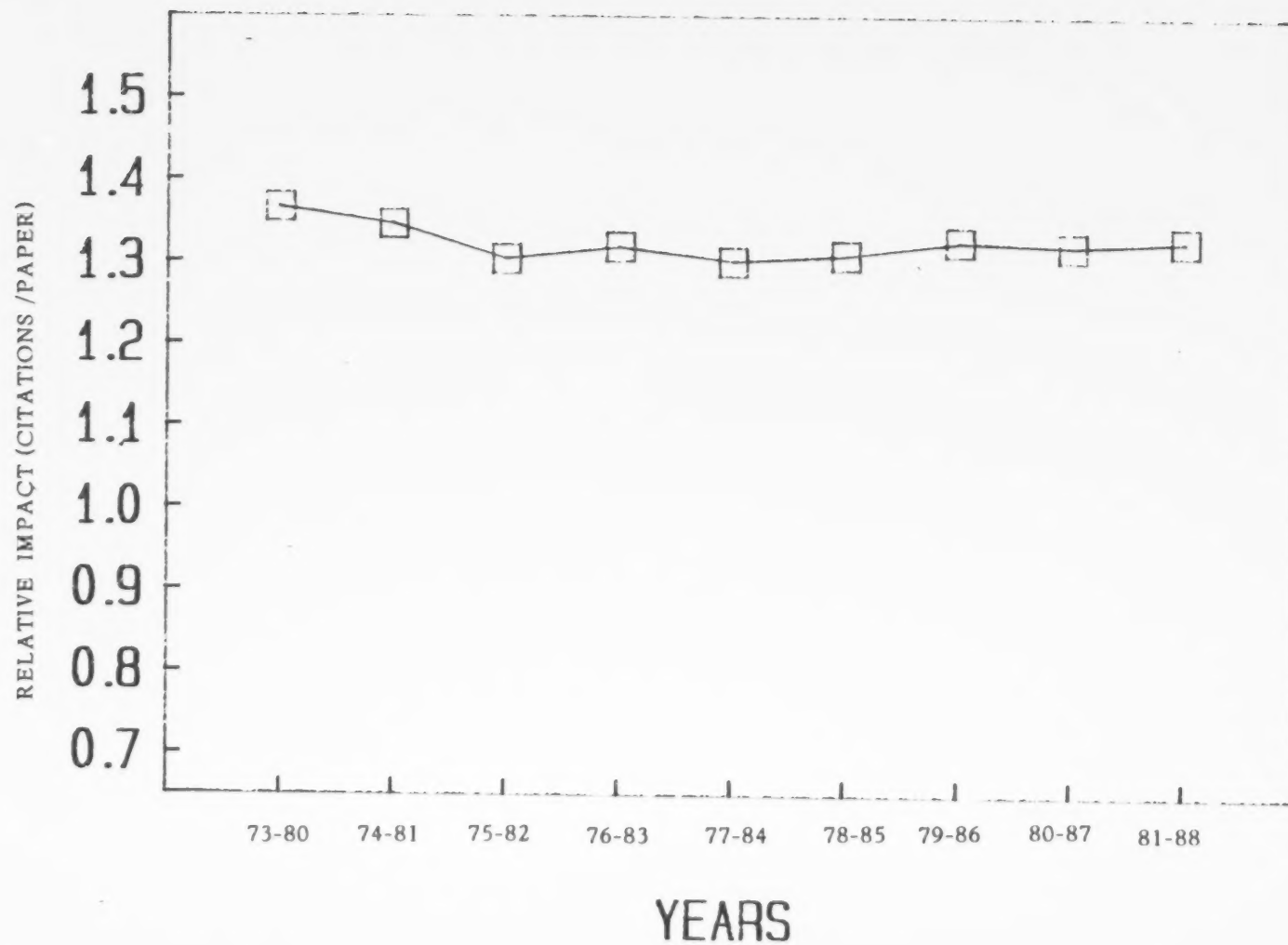


figure 10

UNIV CALIF SANTA BARBARA

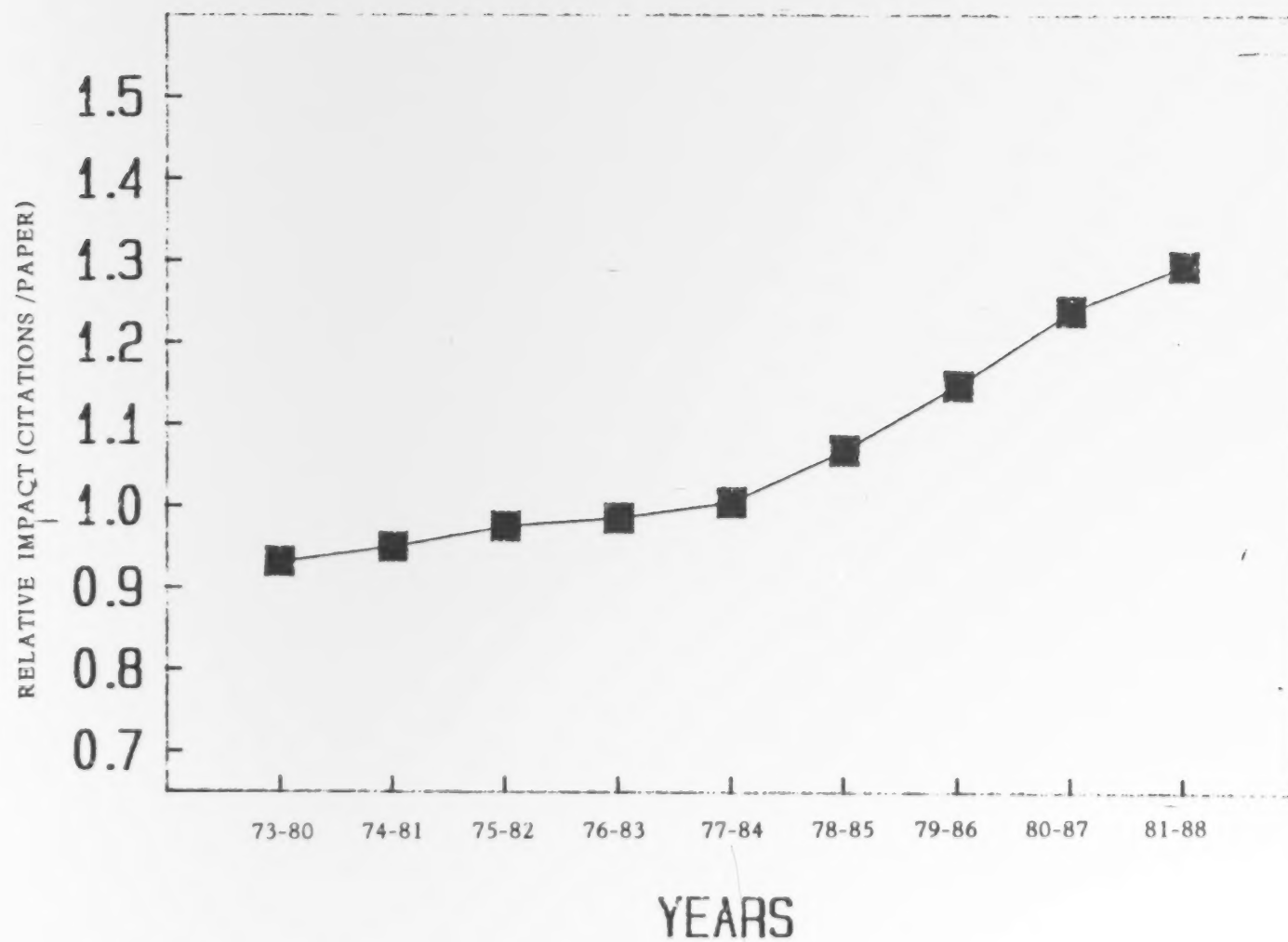


Figure 11

UNIV GEORGIA

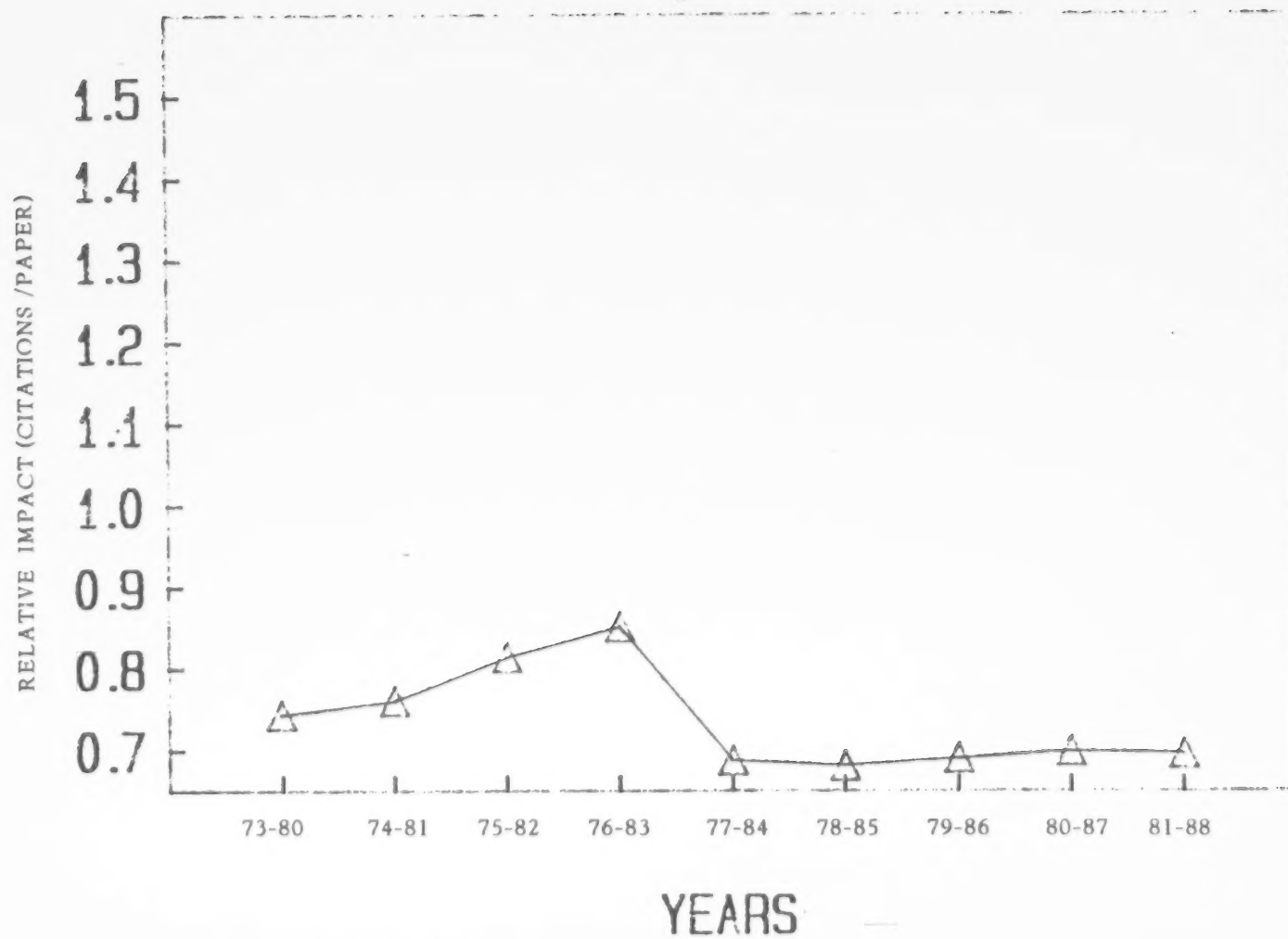


Figure 12

UNIV HOUSTON

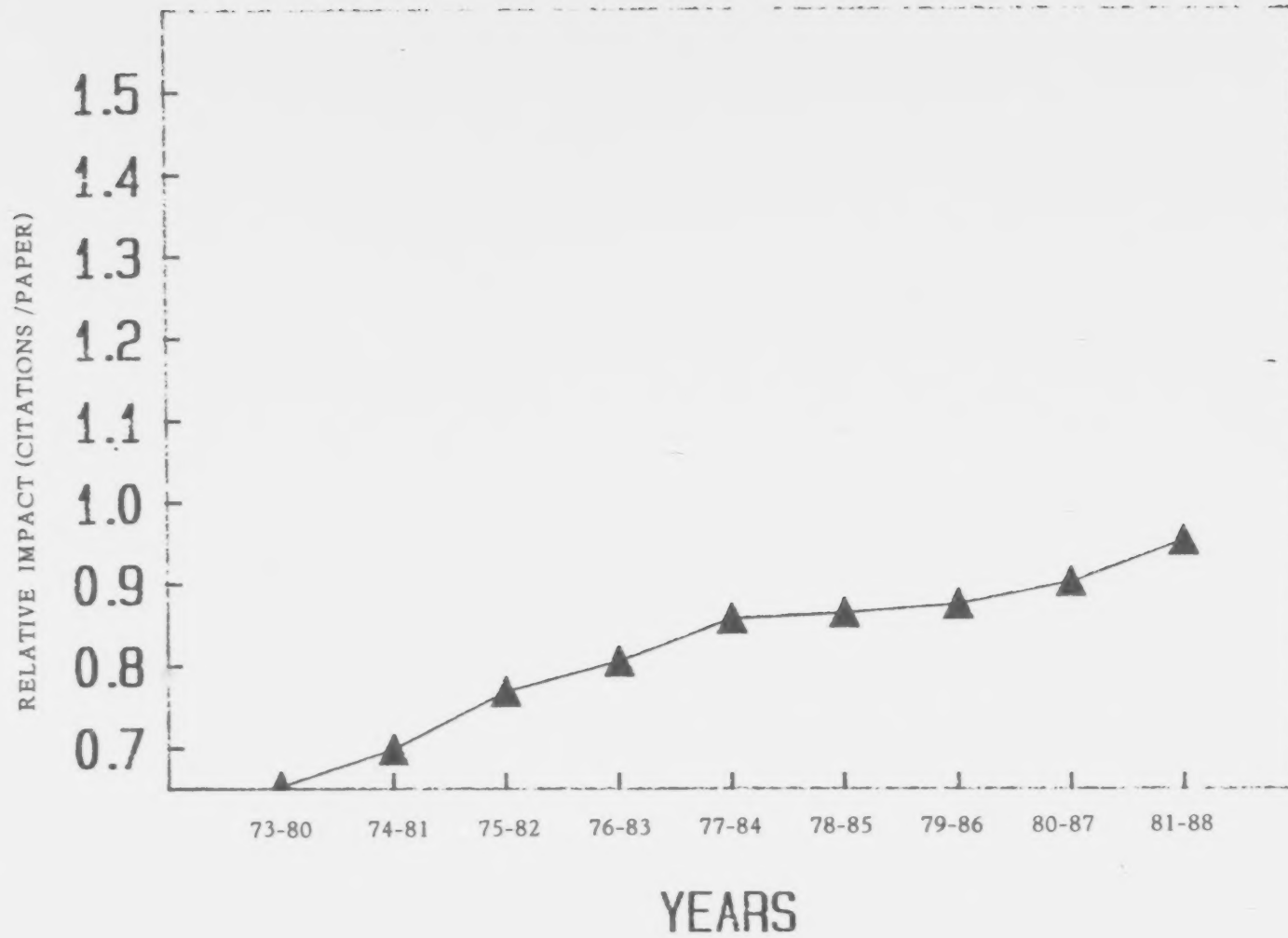


Figure 13

UNIV ILLINOIS

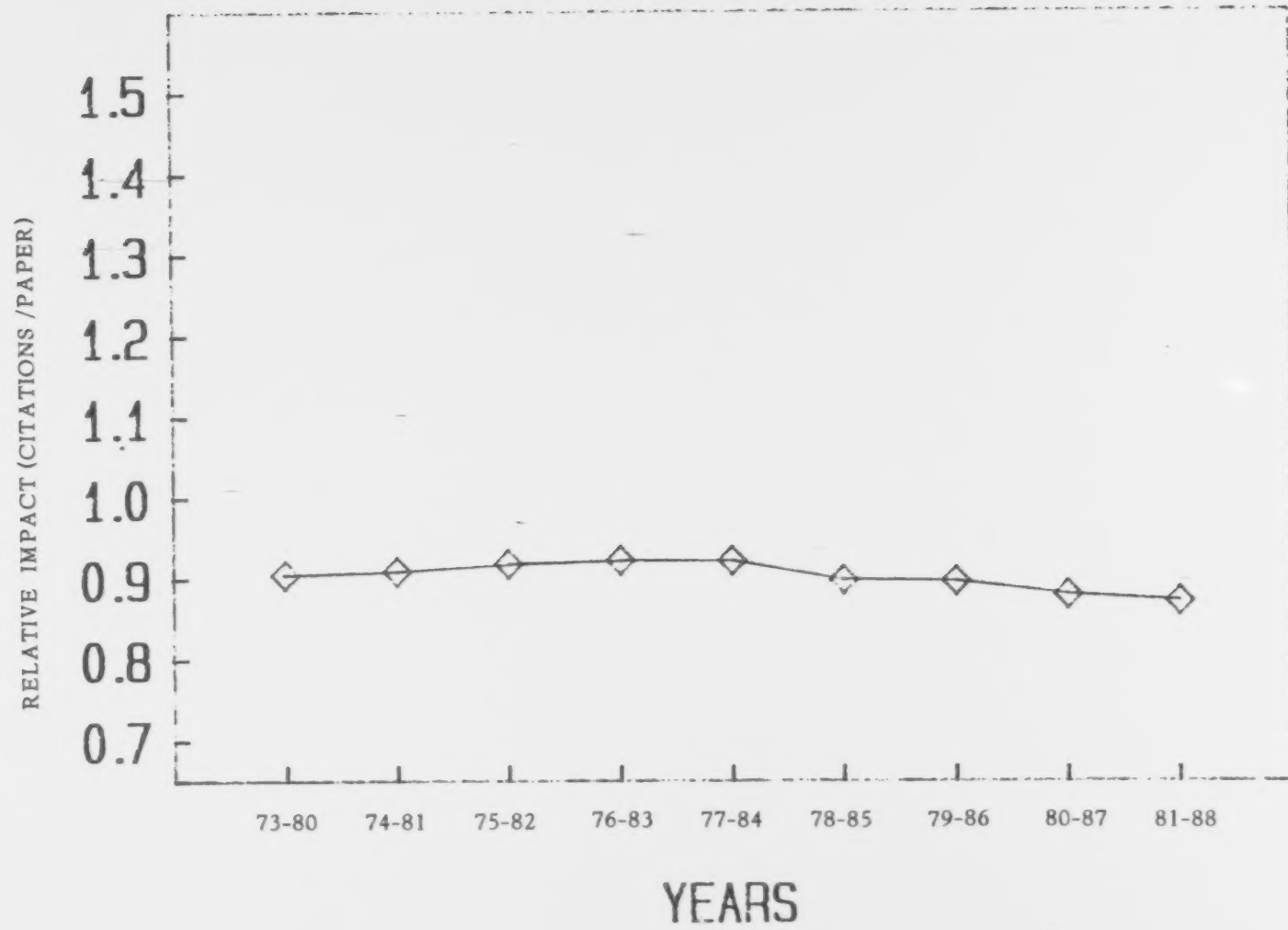


Figure 14

UNIV MARYLAND

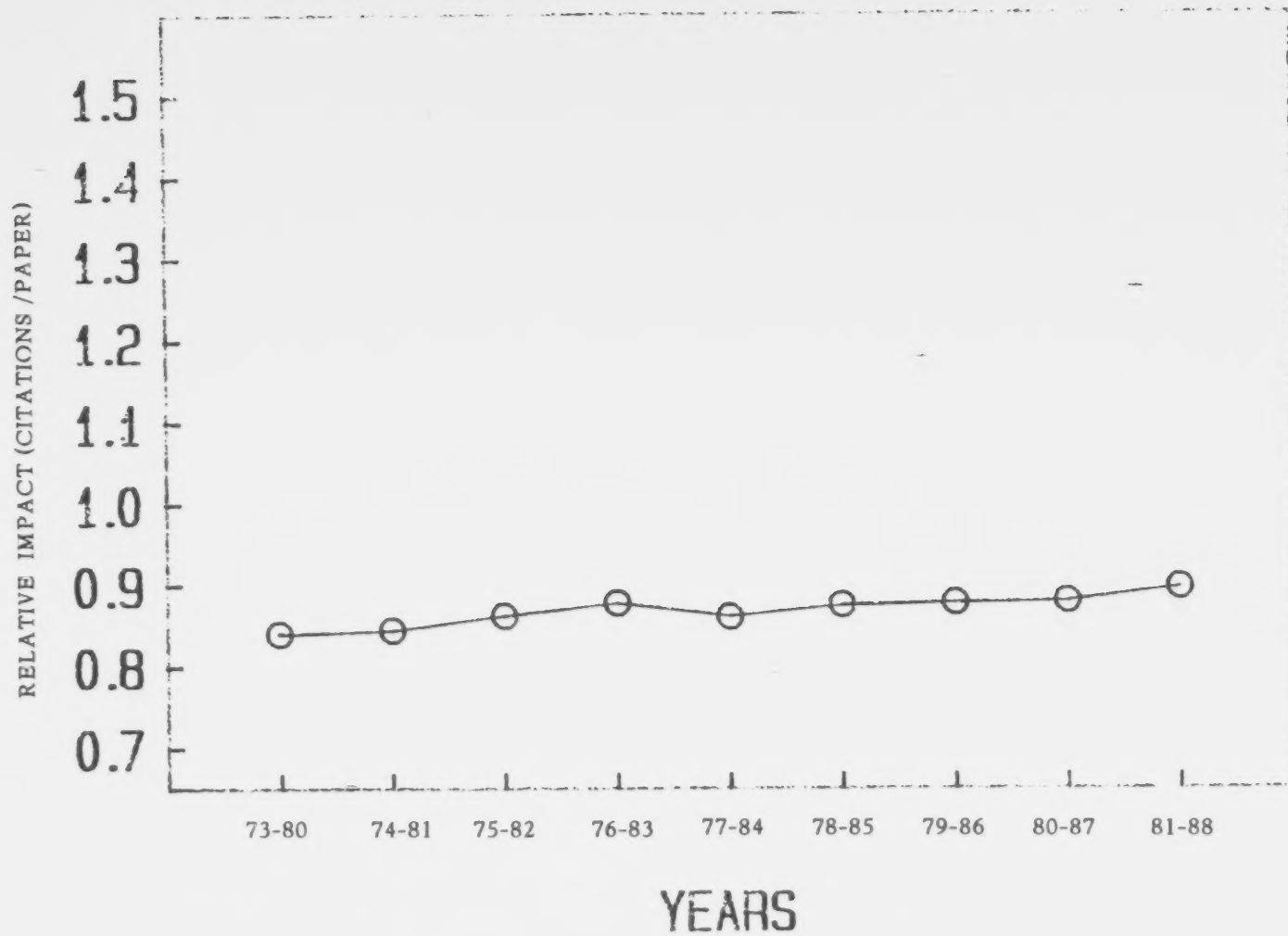


Figure 15

UNIV MASS AMHERST

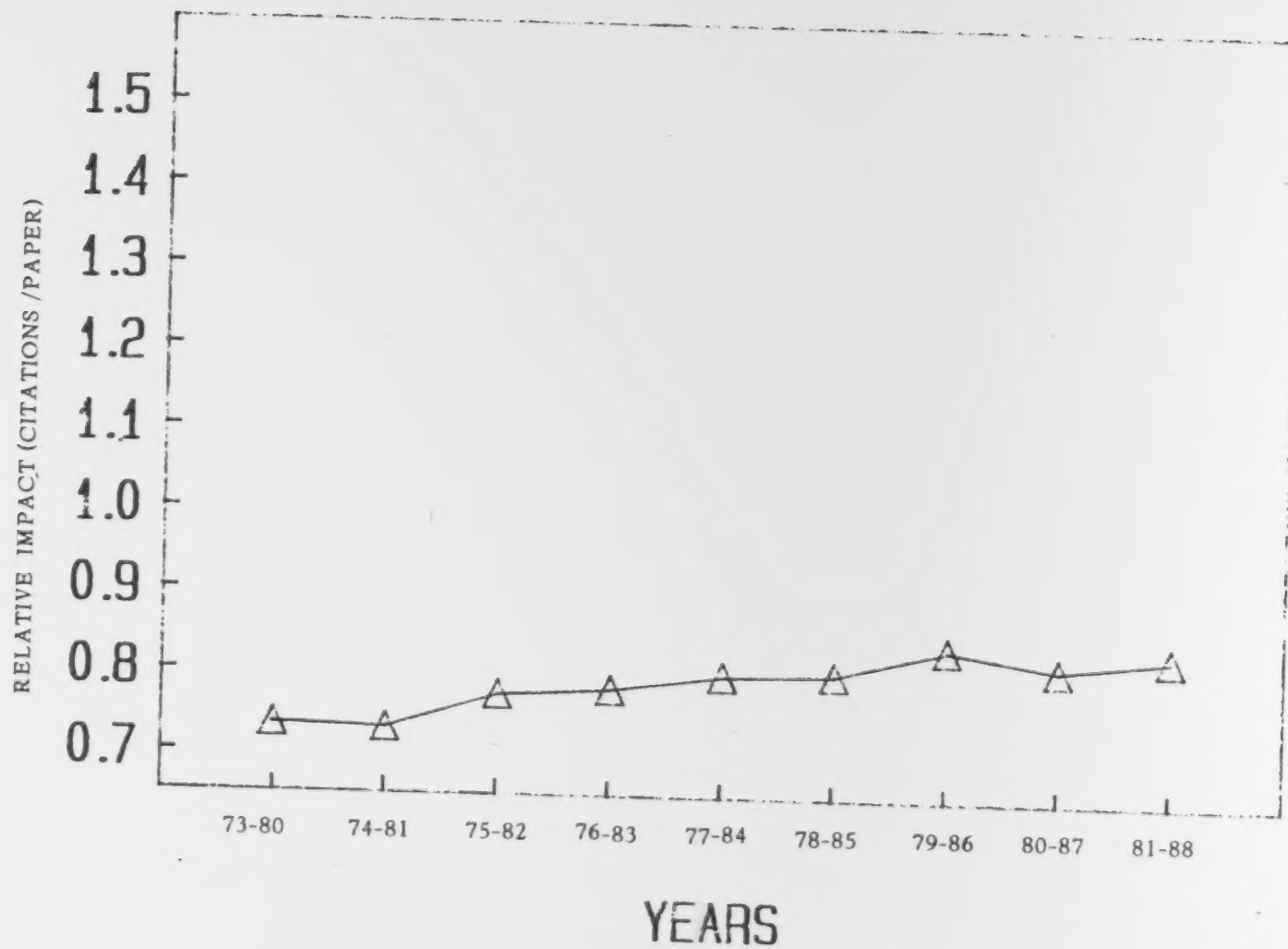


Figure 16

UNIV MICHIGAN

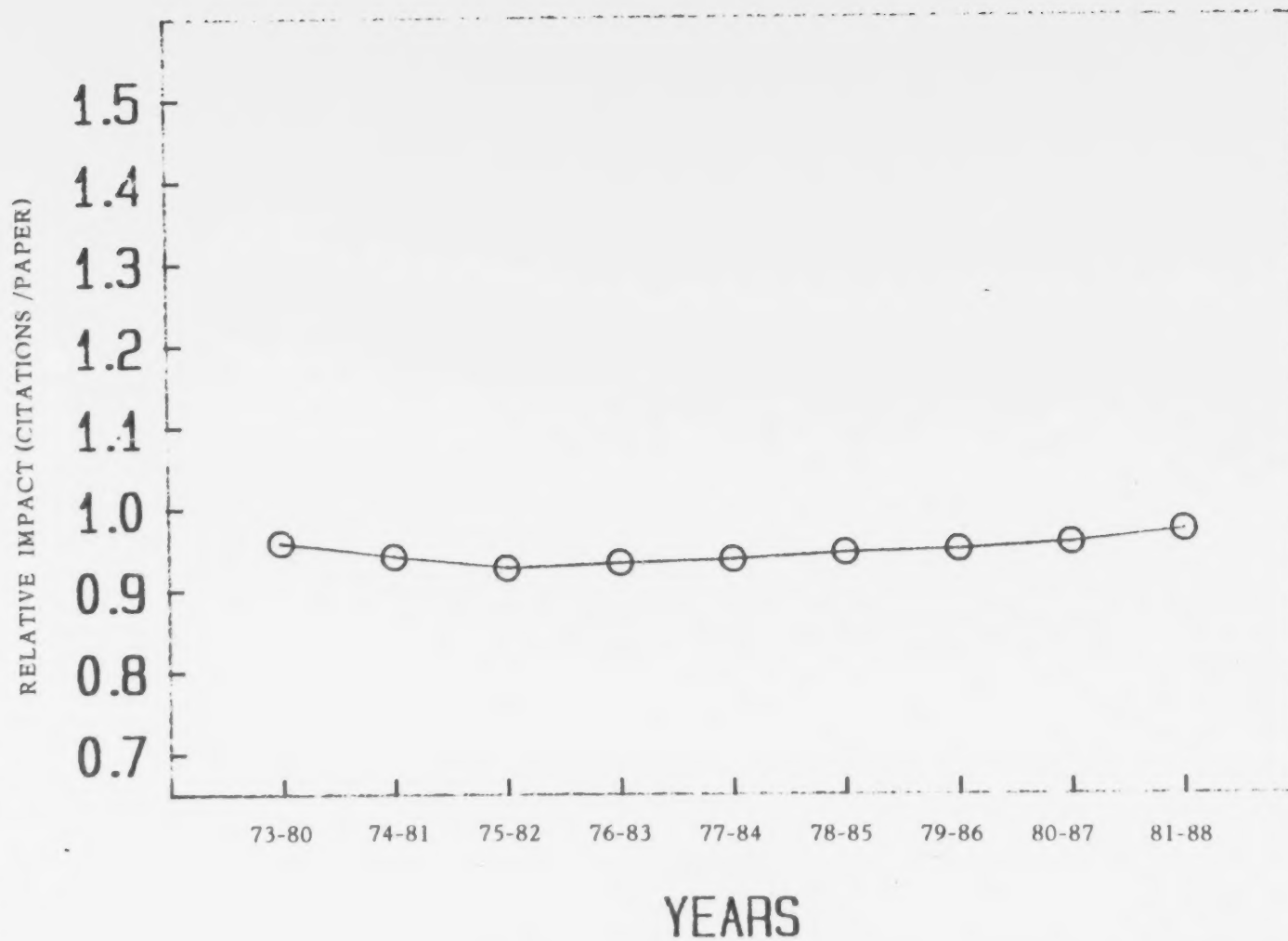
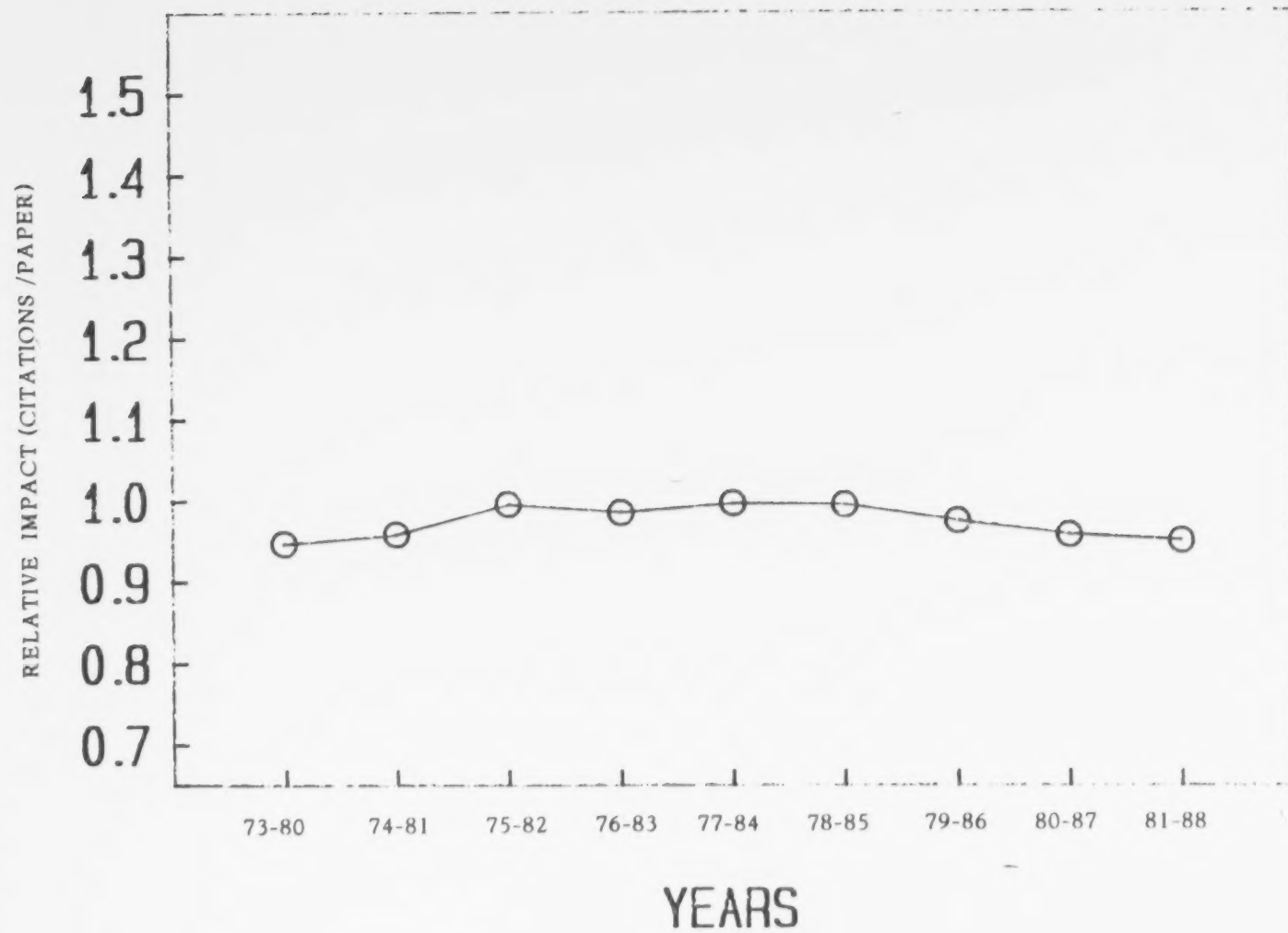


Figure 17

UNIV TEXAS AUSTIN



UNIV WASHINGTON

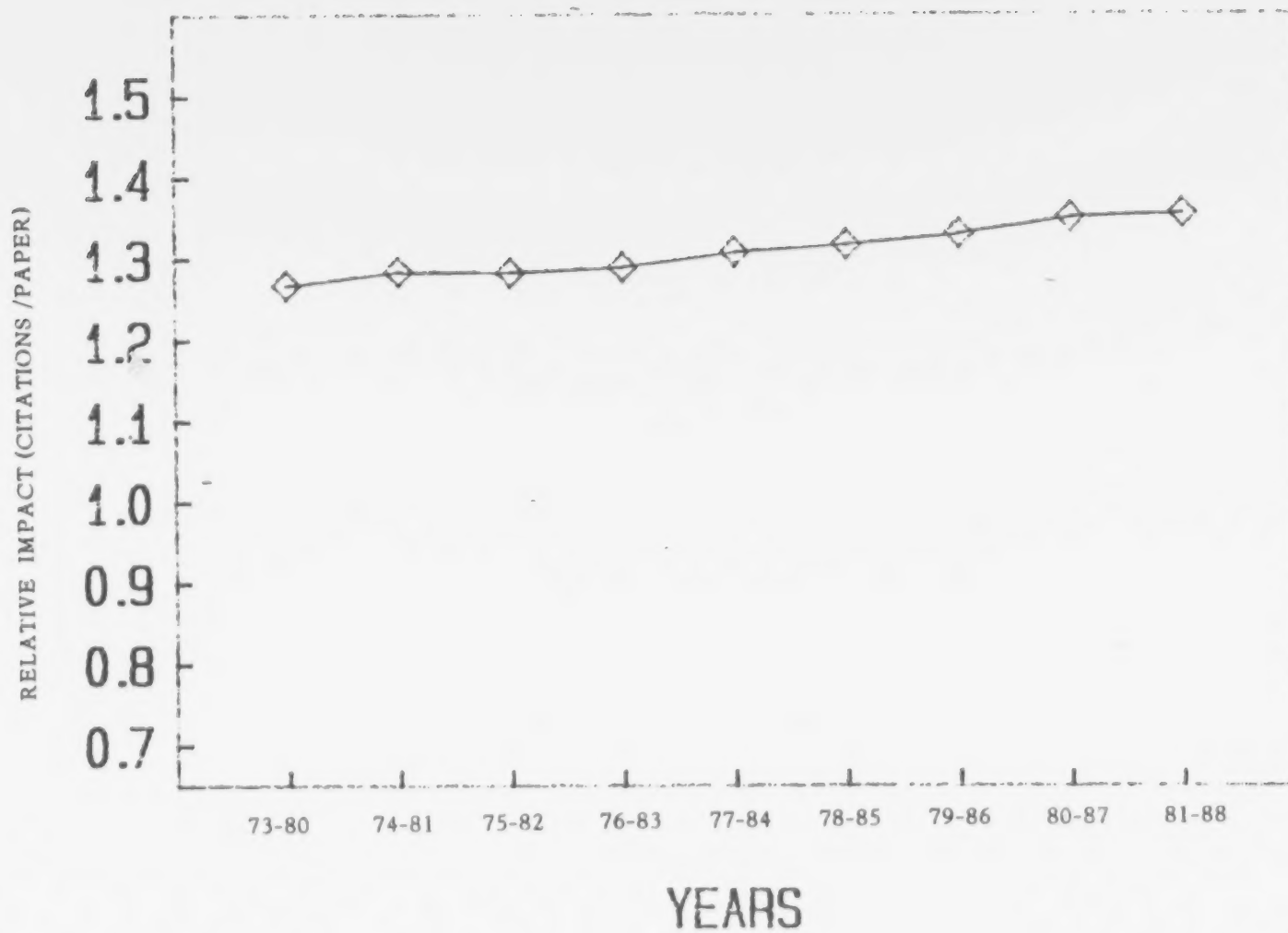
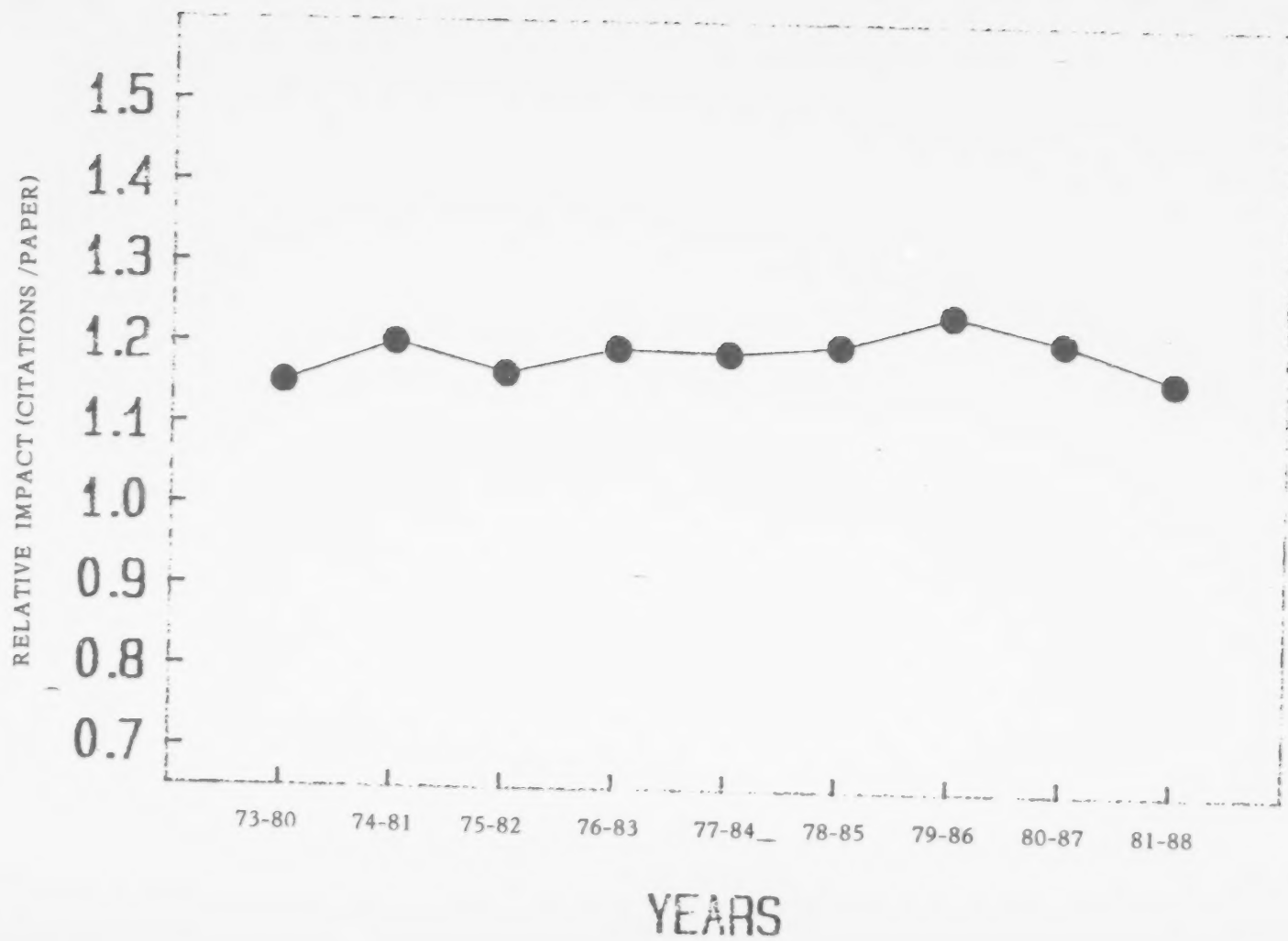


Figure 19

WOODS HOLE



c. Discussion of Task 1

In some of the cases above it may be possible to attribute an increase or decrease in citation impact to a shift in the field orientation of an institution. Such shifts may be the result of deliberate organizational changes or simply a faculty that is able to move into new areas of research. One key to an increasing impact is the ability to produce a continuing flow of innovative papers. This relates to the proportion of the highly cited papers that are of recent origin. Reliance on aging "classics" will not insure an upward trend in impact. Another factor is field balance: some institutions seem to have strength across a number of fields, while other institutions focus on one field seemingly to the exclusion of others. Our inclination is to give the more balanced institution higher marks than the one which is highly specialized.

There are a number of complicating factors in the interpretation of citation impact trends. One is the differential rates at which papers in different subjects accrue citations. Chemistry or biology papers, for example, seem to require a longer period of time to be cited and the volume of citation is lower than for papers in physics or biomedicine. Various strategies might be attempted to get around such problems. One way is to try to define fields by the journals in which the papers are published.(5) Citation norms for journal groupings are then developed. The institution is then composed of several standardized scores, one for each field. The question then becomes how to weight the importance of each field for calculating the institution's overall score. Multidisciplinary journals, however, cannot be handled by this method and it has been proposed to normalize each paper by comparison to the individual journal's citation norm.(6) This method however appears to give too much weight to good articles published in mediocre journals.

At present there does not appear to be a satisfactory solution to the subject normalization problem. Broad journal categories seem to make more sense than narrow subfield categories, since journals at best are only a first approximation to a paper's subject. But the important question may not be what field the papers should be assigned to but what topic the research addresses, e.g. AIDS research, superconductivity, DNA cloning, etc. One can observe in the highly cited paper sets that many of the innovative new papers are not easily categorized in traditional fields, and appear to cut across them, e.g., high temperature superconducting materials research involves both chemistry and physics.

Task 2: New Bibliometric Indicators of Science

The objective of this task is to devise some new types of bibliometric indicators which might be useful for assessing and tracking U.S. basic research. Two of the proposed indicators utilize the ISI Research Front database, as described earlier. The third indicator uses ISI's Science Indicators file, but in a way that differs from its use for tracking individual institutions.

It is our view that the field of science indicators has been far too limited in its aims and methods. Rather than experimenting with and exploring new ways of manipulating bibliographic data to show science from various perspectives, most official efforts have focused on country time series and field or subfield counts based on journal set definitions. While these indicators have given the impression of reliability, objectivity, and consistency, they have not stimulated users of the data to think in new ways about science which may run counter to long held assumptions about how science is structured and progresses. What seems to be needed are new approaches which challenge our assumptions and stimulate critical thinking.

Since bibliometrics involves counting, one issue pertains to how scientific papers are grouped or categorized so that they can be counted. Other issues pertain to what or how to count. The indicators explored below represent only a few possibilities for new directions. The first two take an algorithmic approach to defining the boundaries of research areas, namely cluster analysis. The third indicator explores the use of other kinds of categories which are not internal to science, but rather externally defined.

a. Hot Fields of Science

A fundamental characteristic of co-citation clusters is that they consist of a core of two or more cited documents and a corresponding set of citing papers. The concept of co-citation was in part derived from the association of ideas: if documents stand for ideas, then the act of associating them can lead to new ideas. In actual practice we often find that co-cited papers are different discoveries of the same phenomenon, that is, co-discoveries. Whether co-discoveries or associated ideas, co-cited documents seem to hold more interest and potential than single or isolated ones.

If we combine this notion with the timing of the papers, i.e. how recently the documents were published, we arrive at a possible indicator for "hot fields" of science, that is, co-citation clusters containing at least two documents from the most recent time period. Since our cluster analyses are annual, this would mean that the two cited documents were published in the calendar year of the database used to create the clusters.

In Table 6 we show the 27 research fronts identified using the 1989 ISI database which have two or more core papers published in 1989. Within the list of 27 we have further ordered them by the number of core papers they contain with publication dates within the most recent three year period, namely 1987 through 1989. Thus these fronts are rank on how much recent research they are based upon.

In terms of general subject matter 15 are in biomedical sciences and 12 are in physical sciences. The areas range in size from 800 citing papers for "Alzheimer's disease" to 9 citing papers for "transplantation of abdominal viscera", and from 55 core papers for "endoscopic sphincterotomy" to 2 core papers for the three smallest fronts. The area with the largest number of 1989 core papers is "cold fusion". Even though this field appears to have been discredited, the bibliometric indicators accurately reflect the initial euphoria which surrounded this field, and in some quarters may yet persist. It is interesting that the more traditional approach to fusion represented by cluster #1019 "hydrogen transport; Tokamak fusion test reactor" has nearly twice the number of three-year-old core papers as "cold fusion". The area with the largest number of three-year-old core papers is "endothelin" at the top of the list. "Endothelin" is a newly discovered naturally occurring peptide which has a powerful effect on the cardiovascular and respiratory system.

Another feature of research fronts is that they are often nested at higher levels of aggregation. This nesting is achieved by clustering the clusters themselves, iteratively, a total of four times. The lowest level of aggregation is called C1 and is the level which has been used in identifying hot fields in the previous table. C2 is the next higher level of aggregation and is a cluster analysis of all C1 clusters. This level corresponds roughly to scientific specialty. C3, the third aggregation level, most nearly represents the traditional field of science, and C4 can represent entire disciplines such as physical science or biomedicine.

Table 7 is a hierarchical listing of the 27 hot fields of Table 6, showing the four levels of cluster numbers. Eight of the areas are isolated fields, the largest of these being cold fusion. Isolation means that no inter-cluster links could be found strong enough to bring an area together with any other area in the file of roughly 8,000 research fronts. It is often the case that a new or radically different area begins as an isolate, simply because it is too new to integrate with the main body of science. Three of the areas are members of isolated C2 groups, i.e. they are grouped at C2 but not at higher levels. These represent an intermediate state of isolation. All three are biomedical and when each of their C2 groups is examined we find other similar biomedical areas associated with them. The hepatitis-B area is associated with several other areas dealing with other forms of hepatitis. The endoscopic sphincterotomy area is associated with other areas on gallstone disease and the litho-

tripsy method applied to other organs. The transplantation area is likewise associated with other experimental forms of organ transplantation.

Fifteen of the fields in Table 7 are integrated into the level C4 #1 region, which is a very large multidisciplinary mix of biomedical and physical science areas of basic research. Hence the majority of the hot fields are in what might be called main stream science. For purposes of seeing subject relationships, it is more informative to look at the C3 level cluster numbers than the C4. For example, there are three clusters belonging to C3 #5, which is a physics category dealing with high temperature superconductivity and other aspects of electrical conduction, including narrow channel conductance (C1 #915). Two clusters belong to another physics C3, namely #6, which includes the particle physics area on light bosons and the astrophysics cluster on the supernova. Two medical clusters, the one on endothelin and the one on prostate enlargement, fall in C3 #8. The hot fusion cluster falls into a separate C4 group, namely C4 #4, which is a separate grouping of research areas on plasma physics and related topics, which has not been drawn into the main physics groupings in C4 #1.

It is often the case that hot fields belong to higher level groups which contain other moderately hot areas. This is the case for 14 of the 19 hot areas which belong to higher level groups. This is indicated by a "yes" following the cluster name on Table 7. For example, one of the hot areas on high temperature superconductivity (C1 #436) is surrounded by other hot clusters which aggregate at the C2 level (see Table 8). Another example is the cluster on national health insurance (Table 9). It is grouped together with other moderately hot areas dealing with various topics in medical ethics.

The previous analysis suggests that the identification of hot fields could proceed at a higher level of aggregation, for example at C2 rather than C1, giving a broader scope to the categories without however losing topic specificity which can occur if clusters become too broad.

The final aspect of hot fields which we will discuss is their international character. This is summarized in Table 10 which lists for each hot field in Table 6 the two countries which contribute papers to the field at the highest rate above their expected levels. The expected level for a country is calculated by taking the number of papers produced by a country as a percentage of the total number of papers in the research front database. To determine the degree a country contributes above the expected rate, we divide the country's percentage contribution to the cluster by the expected percentage for that country. This gives the number of time the country's contribution is over the expected level. These numbers are given in Table 10 following each of the two top countries in the columns labeled "OVER". Only countries having more than 2.5 percent of the total research front publications are included in this table. A blank

indicates that these major countries did not contribute to the area above their expected levels. The table also contains a code for whether the field is physical science oriented (P) or biomedical science oriented (B), and an abbreviated clusters name.

We see that cluster 868 on the Edgecumbe earthquake was not participated in by major countries. In fact, this is an example of a geographically localized hot field, almost all the papers coming from New Zealand, the site of the quake in 1987. Cluster 5191 dealing with sexual behavior and HIV infection was dominated by England. This is an exception rather than the rule since most AIDS areas are international in character. In terms of which countries participate above expected levels in the most hot fields, England was first with eleven and US was second with nine. Japan and the Federal Republic of Germany were next with eight areas, followed by Italy with seven. Finally, France and Canada were in three areas, and the USSR was in fewest areas with two.

It was also of interest to see the balance of biomedical and physical science topics in the various countries, keeping in mind that there were 15 biomedical areas and 12 physical science areas. Countries which participated in mostly biomedical hot fields were the US, England and Canada, while physical science fields were more prevalent in Japan, FRG, and the USSR. Italy and France were balanced between the physical and biomedical.

Table 6
HOT FIELDS OF 1989

Page 1

C1	CITING CORE	HOT3	HOT1	NAME
1398	587	37	28	3 ENDOTHELIN STIMULATES RELEASE; RAT CARDIAC MEMBRANES; VASCULAR SMOOTH-MUSCLE; SYSTEMIC VASOCONSTRICTOR PEPTIDE
90	800	48	26	2 ALZHEIMERS-DISEASE AMYLOID PRECURSOR PROTEIN; DIFFERENTIAL BRAIN EXPRESSION; REACTIVE ASTROCYTES FOLLOWING NEURONAL DAMAGE
2726	278	40	24	6 NATIONAL-HEALTH PROGRAM; UNIVERSAL INSURANCE; UNITED-STATES EXPERIENCE; FINANCIAL INCENTIVES; CANADIAN REALITY; OFFICE VISIT COPAYMENTS; COST CONTAINMENT
1019	233	36	21	2 HYDROGEN TRANSPORT; TOKAMAK FUSION TEST REACTOR; HIGH-FLUX PLASMA BOMBARDMENT; CARBON WALLS; IMPURITY PRODUCTION AT GRAPHITE LIMITERS; EROSION BEHAVIOR
41	616	51	19	2 LIGHT HIGGS BOSON; QUARK MASS MATRICES; CP VIOLATION; PHYSICS OF B-MESONS; WEAK DECAYS; CHARGE ASYMMETRIES
436	605	27	17	4 HIGH-TC SUPERCONDUCTORS; SINGLE-CRYSTAL LA ₂ CUO ₄ ; MIXED-VALENCE COPPER OXIDES
623	366	55	17	2 ENDOSCOPIC SPHINCTEROTOMY FOR BILE-DUCT STONES; BILIARY LITHOTRIPSY; GALLSTONE DISEASE
915	278	29	17	2 QUANTUM POINT CONTACTS; BALLISTIC TRANSPORT; QUANTIZED CONDUCTANCE OF NARROW CHANNELS; HALL RESISTANCE
4068	234	28	17	2 ANTARCTIC OZONE HOLE; POLAR STRATOSPHERIC CLOUDS ; INSITU ER-2 DATA
1038	261	35	14	3 NONIONIC CONTRAST-MEDIA; META-ANALYSIS IN MEDICINE; RANDOMIZED CONTROLLED TRIALS; THROMBOEMBOLIC COMPLICATIONS
1461	448	42	13	6 ADJUVANT THERAPY FOR NODE-NEGATIVE BREAST-CANCER ; MORTALITY PATTERNS; COMBINATION CHEMOTHERAPY
557	242	25	12	9 COLD FUSION; PAIR INTERACTION ENERGY OF HYDROGEN ISOTOPES; PALLADIUM CATHODES IN ELECTROLYTIC CELLS
123	137	18	9	2 BENIGN PROSTATIC HYPERPLASIA; INTRAVASCULAR STENTS; TRANS-URETHRAL RESECTION; OBSTRUCTION OF URINARY OUTFLOW

C1	CITING CORE	HOT3	HOT1	NAME
2	296	35	9	2 CHRONIC HEPATITIS-B; INTERFERON THERAPY; RANDOMIZED CONTROLLED TRIAL OF ADENINE-ARABINOSIDE 5'-MONOPHOSPHATE
4726	54	8	7	2 ER-3+-DOPED FIBER AMPLIFIER; OPTICAL GAIN SPECTRUM; CONTINUOUS WAVE 16-MUM LASER ACTION
3291	40	6	5	2 TRENDS IN CIGARETTE-SMOKING PREVALENCE; HARD-CORE SMOKERS; LUNG-CANCER MORTALITY
868	21	4	4	3 1987 EDGE CUMBE EARTHQUAKE, NEW-ZEALAND; SEISMIC DESIGN CONSIDERATIONS FOR BURIED PIPELINES; ATTENUATION OF STRONG GROUND MOTION
4196	383	15	4	2 TRANSFERRIN RECEPTOR; ACTION OF CYCLOSPORINE; PEPTIDYL-PROLYL ISOMERASE ACTIVITY; CYTO-TOXIC T-CELLS; HUMAN IL-2 GENE; TARGETS FOR INHIBITION
3403	74	12	4	2 ASYMMETRIC HOMOALDOL REACTION; DIELS-ALDER CYCLOADDUCT; REGIOSPECIFIC FORMATION; ESTER HOMOENOLATE EQUIVALENT
6894	24	3	3	3 CYSTIC-FIBROSIS GENE; AMPLIFICATION REFRACTORY MUTATION SYSTEM; CARRIER ASSESSMENT
8162	25	3	3	3 POLYMERASE CHAIN-REACTION; HUMAN PAPILLOMAVIRUS TYPE-16 DNA; CERVICAL INTRAEPITHELIAL NEOPLASIA; ANAL CANCER
1185	79	7	3	3 NEUTRON STAR IN SUPERNOVA 1987A; SUB-MILLISECOND PULSAR; STRANGE MATTER
2269	41	7	3	2 PHOTON FACTORY; 53-POLE WIGGLER UNDULATOR BEAMLINE; SYNCHROTRON RADIATION; OPTICAL-CONSTANTS FOR COATED THIN-FILMS; REFLECTANCE SPECTRA OF IMPLANTED GAAS
3779	61	3	3	2 HIGH-TEMPERATURE OXIDE SUPERCONDUCTORS; LEAD CUPRATES; OXYGEN DISPLACEMENTS
5191	14	2	2	2 RISK-FACTORS FOR HIV INFECTION; SEXUAL-BEHAVIOR IN HOMOSEXUAL MEN; RESURGENCE OF HETEROSEXUALLY ACQUIRED EARLY SYPHILIS
8112	9	2	2	2 TRANSPLANTATION OF ABDOMINAL VISCERA

C1	CITING	CORE	HOT3	HOT1	NAME
450	13	2	2	2	PRIMARY ANTIPHOSPHOLIPID SYNDROME; HEPARIN-INDUCED THROMBOCYTOPENIA; HEMORRHAGIC NECROSIS

Table 7

Hierarchical Cluster Memberships for Hot Fields

Page 1

HOT
GROUP

C4	C3	C2	C1	CORE	NAME	
0	0	0	450	2	PRIMARY ANTIPHOSPHOLIPID SYNDROME; HEPARIN-INDUCED THROMBOCYTOPENIA; HEMORRHAGIC NECROSIS	
0	0	0	557	25	COLD FUSION; PAIR INTERACTION ENERGY OF HYDROGEN ISOTOPES; PALLADIUM CATHODES IN ELECTROLYTIC CELLS	
0	0	0	868	4	1987 EDGE CUMBE EARTHQUAKE, NEW-ZEALAND; SEISMIC DESIGN CONSIDERATIONS FOR BURIED PIPELINES; ATTENUATION OF STRONG GROUND MOTION	
0	0	0	2269	7	PHOTON FACTORY; 53-POLE WIGGLER UNDULATOR BEAMLINE; SYNCHROTRON RADIATION; OPTICAL-CONSTANTS FOR COATED THIN-FILMS; REFLECTANCE SPECTRA OF IMPLANTED GAAS	
0	0	0	3291	6	TRENDS IN CIGARETTE-SMOKING PREVALENCE; HARD-CORE SMOKERS; LUNG-CANCER MORTALITY	
0	0	0	3403	12	ASYMMETRIC HOMOALDOL REACTION; DIELS-ALDER CYCLOADDUCT; REGIOSPECIFIC FORMATION; ESTER HOMOENOLATE EQUIVALENT	
0	0	0	5191	2	RISK-FACTORS FOR HIV INFECTION; SEXUAL-BEHAVIOR IN HOMOSEXUAL MEN; RESURGENCE OF HETEROSEXUALLY ACQUIRED EARLY SYPHILIS	
0	0	0	6894	3	CYSTIC-FIBROSIS GENE; AMPLIFICATION REFRACTORY MUTATION SYSTEM; CARRIER ASSESSMENT	
0	0	1	2	35	CHRONIC HEPATITIS-B; INTERFERON THERAPY; RANDOMIZED CONTROLLED TRIAL OF ADENINE-ARABINOSIDE 5'-MONOPHOSPHATE	NC
0	0	80	623	55	ENDOSCOPIC SPHINCTEROTOMY FOR BILE-DUCT STONES; BILIARY LITHOTRIPSY; GALLSTONE DISEASE	YES
0	0	741	8112	2	TRANSPLANTATION OF ABDOMINAL VISCERA	YES
1	2	671	4196	15	TRANSFERRIN RECEPTOR; ACTION OF CYCLOSPORINE; PEPTIDYL-PROLYL ISOMERASE ACTIVITY; CYTO-TOXIC T-CELLS; HUMAN IL-2 GENE; TARGETS FOR INHIBITION	YES
1	4	6	2726	40	NATIONAL-HEALTH PROGRAM; UNIVERSAL INSURANCE; UNITED-STATES EXPERIENCE; FINANCIAL INCENTIVES; CANADIAN REALITY; OFFICE VISIT CO-PAYMENTS; COST CONTAINMENT	YES

Table 7 continued

						Page	2	HOT GROUP
C4	C3	C2	C1	CORE	NAME			
1	5	66	915	29	QUANTUM POINT CONTACTS; BALLISTIC TRANSPORT; QUANTIZED CONDUCTANCE OF NARROW CHANNELS; HALL RESISTANCE			YES
1	5	102	436	27	HIGH-TC SUPERCONDUCTORS; SINGLE-CRYSTAL LA ₂ CUO ₄ ; MIXED-VALENCE COPPER OXIDES			YES
1	5	795	3779	3	HIGH-TEMPERATURE OXIDE SUPERCONDUCTORS; LEAD CUPRATES; OXYGEN DISPLACEMENTS			YES
1	6	17	41	51	LIGHT HIGGS BOSON; QUARK MASS MATRICES; CP VIOLATION; PHYSICS OF B-MESONS; WEAK DECAYS; CHARGE ASYMMETRIES			YES
1	6	445	1185	7	NEUTRON STAR IN SUPERNOVA 1987A; SUB-MILLISECOND PULSAR; STRANGE MATTER			YES
1	8	12	123	18	BENIGN PROSTATIC HYPERPLASIA; INTRAVASCULAR STENTS; TRANS-URETHRAL RESECTION; OBSTRUCTION OF URINARY OUTFLOW			YES
1	8	12	1398	37	ENDOTHELIN STIMULATES RELEASE; RAT CARDIAC MEMBRANES; VASCULAR SMOOTH-MUSCLE; SYSTEMIC VASOCONSTRICTOR PEPTIDE			YES
1	13	55	90	48	ALZHEIMERS-DISEASE AMYLOID PRECURSOR PROTEIN; DIFFERENTIAL BRAIN EXPRESSION; REACTIVE ASTROCYTES FOLLOWING NEURONAL DAMAGE			NO
1	35	97	4726	8	ER-3+-DOPED FIBER AMPLIFIER; OPTICAL GAIN SPECTRUM; CONTINUOUS WAVE 16-MUM LASER ACTION			YES
1	41	512	1461	42	ADJUVANT THERAPY FOR NODE-NEGATIVE BREAST-CANCER; MORTALITY PATTERNS; COMBINATION CHEMOTHERAPY			NO
1	48	915	4068	28	ANTARCTIC OZONE HOLE; POLAR STRATOSPHERIC CLOUDS; INSITU ER-2 DATA			NO
1	96	437	8162	3	POLYMERASE CHAIN-REACTION; HUMAN PAPILLOMAVIRUS TYPE-16 DNA; -CERVICAL INTRAEPITHELIAL NEOPLASIA; ANAL CANCER			YES
1	98	375	1038	35	NONIONIC CONTRAST-MEDIA; META-ANALYSIS IN MEDICINE; RANDOMIZED CONTROLLED TRIALS; THROMBOEMBOLIC COMPLICATIONS			NO

Table 7 continued

Page 3

HOT
GROUP

C4	C3	C2	C1	CORE	NAME	
4	87	308	1019	36	HYDROGEN TRANSPORT; TOKAMAK FUSION TEST REACTOR; HIGH-FLUX PLASMA BOMBARDMENT; CARBON WALLS; IMP URITY PRODUCTION AT GRAPHITE LIMITERS; EROSION B EHAVIOR	YES

Table 8
Research Fronts Arranged Hierarchically Showing Related Hot Fields

C1 1989 RANK	ALL C4	CLUSTER C3	INVENTORY C2	C1 CORE	CITING CITE/CO	FIELD= 1 IMMED3	SRT C4-C3-C2-C1 IM-PR3	IMMED1	AV-AGE	RAN ON 05/07/90 AT 18:12:59 CLUSTER --NAME--	PAGE-00440	
5544	1	5	78	7935	2	27	14	0	0	0	70	IRON COMPLEXES; LOW-LYING STATES; METALS IN BIOLOGY
5545	1	5	101	179	45	649	14	1	2	0	75	INTERACTION IN HALIDE ION RARE-GAS SYSTEMS; SPECTRAL DECONVOLUTION; LINEAR INVERSION; MAXIMUM-ENTROPY ANALYSIS OF PHOTON-CORRELATION SPECTROSCOPY DATA
5546	1	5	101	7054	2	57	29	0	0	0	55	UNIFIED FRAMEWORK; STOCHASTIC INPUT OUTPUT DATA; KULLBACK LEIBLER INFORMATION
5547	1	5	102	180	51	572	11	51	100	1	88	Y-BA-CU-O SUPERCONDUCTING THIN-FILMS; PULSED LASER DEPOSITION; MAGNETRON SPUTTERING
5548	1	5	102	182	5	52	10	5	100	0	88	ORGANOMETALLIC CHEMICAL VAPOR-DEPOSITION OF HIGH-TC SUPERCONDUCTING BI-SR-CA-CU-O FILMS; LASER ABLATION; STRUCTURE FORMATION
5549	1	5	102	294	15	193	13	15	100	1	88	MAGNETIC PENETRATION DEPTH; HIGH-TC SUPERCONDUCTORS; YBA2CU3O7 THIN-FILMS
5550	1	5	102	300	41	910	22	27	66	1	86	HIGH-TC SUPERCONDUCTIVITY; FRACTIONAL STATISTICS; TWO-DIMENSIONAL QUANTUM HEISENBERG-ANTIFERROMAGNETISM; CHERN-SIMONS TERM; RESONATING-VALENCE-BOND STATES
5551	1	5	102	435	59	2055	35	58	98	0	88	HIGH-TC SUPERCONDUCTORS; MIXED-VALENCE COPPER OXIDES; 110 K PHASE IN PB-SUBSTITUTED BI-SR-CA-CU-O
5552	1	5	102	436	27	605	22	17	63	4	84	HIGH-TC SUPERCONDUCTORS; SINGLE-CRYSTAL LA2CUO4; MIXED-VALENCE COPPER OXIDES
5553	1	5	102	564	4	73	18	4	100	0	88	YBA2CU3O7-X SUPERCONDUCTING CERAMICS; MELT PROCESSING; HIGH-TC OXIDES
5554	1	5	102	626	5	105	21	0	0	0	77	HIGH-TC SUPERCONDUCTIVITY; DIAMOND ANVIL CELL; ELECTRON-PHONON RELAXATION RATE IN SINGLE-CRYSTAL LANTHANUM CUPRATE
5555	1	5	102	638	2	54	27	0	0	0	69	HIGH-TC SUPERCONDUCTIVITY; STUDIES OF ORGANIC SEMICONDUCTORS; LAO BAO SRO OXYGEN(P)-METAL(D) EXCITONS
5556	1	5	102	751	2	66	33	0	0	0	63	SMALL SUPERCONDUCTING TUNNEL-JUNCTIONS; CERAMIC YB

C1 1989
RANK C4

5704 1

5705 1

5706 1

5707 1

5708 1

5709 1

5710 1

5711

5712

5713

5714

5715

SRT C4-C3-C2-C1, 1

B 3

SRT C

Table 9
Hierarchical Research Fronts Showing Related Hot Fields

C1 1989 ALL CLUSTER INVENTORY	FIELD= 1	SRT C4-C3-C2-C1	RAN ON 05/07/90 AT 18:12:59	PAGE-00425
RANK C4 C3 C2 C1 CORE CITING CITE/CO IMMED3 IM-PR3 IMMED1 AV-AGE	CLUSTER --NAME--			
5361 1 4 6 2206 2 38 19 0 0 0 85	CYCLOSPORINE NEPHROTOXICITY; CARDIAC TRANSPLANTATI ON; POSTTRANSPLANT HYPERTENSION			
5362 1 4 6 2365 12 189 16 3 25 0 85	CYCLOSPORINE NEPHROTOXICITY; EARLY RENAL INJURY; T HROMBOTIC MICROANGIOPATHY FOLLOWING ALLOGENEIC BON E-MARROW TRANSPLANTATION			
5363 1 4 6 2726 40 278 7 24 60 6 86	NATIONAL-HEALTH PROGRAM; UNIVERSAL INSURANCE; UNIT ED-STATES EXPERIENCE; FINANCIAL INCENTIVES; CANADI AN REALITY; OFFICE VISIT COPAYMENTS; COST CONTAINM ENT			
5364 1 4 6 2770 23 208 9 7 30 0 84	PERIOPERATIVE BLOOD-TRANSFUSION; PSYCHIATRIC ASPEC TS OF RENAL-TRANSPLANTATION; HLA COMPATIBILITY; RE CURRENCE IN COLORECTAL-CANCER			
5365 1 4 6 3605 5 64 13 3 60 0 87	NURSING ETHICS; ANENCEPHALIC TISSUE FOR TRANSPLANT ATION; AGE CRITERIA			
5366 1 4 6 3611 8 95 12 4 50 0 84	RENAL-ALLOGRAFT RECIPIENTS; CYCLOSPORINE NEPHROTOX ICITY; CUTANEOUS T-CELL LYMPHOMA; DOUBLE-BLIND CON TROLLED TRIAL OF AZATHIOPRINE; ELECTIVE CONVERSION			
5367 1 4 6 3642 5 44 9 1 20 0 86	CYCLOSPORINE THERAPY IN PRIMARY CADAVERIC RENAL-TR ANSPLANT RECIPIENTS; DELAYED GRAFT FUNCTION; ANTI LYMPHOCYTE GLOBULIN; EARLY POSTTRANSPLANT DYSFUNCTI ON			
5368 1 4 6 3807 13 144 11 0 0 0 84	PHARMACOKINETICS OF NIFEDIPINE; DILTIAZEM PLASMA-L EVELS; DIFFERENT ORAL DOSAGE FORMS IN HEALTHY-VOLU NTEERS			
5369 1 4 6 4109 2 9 5 0 0 0 81	HIGH-PERFORMANCE LIQUID-CHROMATOGRAPHY; METABOLITE S IN HUMAN-PLASMA; DILTIAZEM HYDROCHLORIDE			
5370 1 4 6 4720 14 88 6 5 36 0 86	DRG PROSPECTIVE HOSPITAL PAYMENT; HEALTH-CARE FINA NCING POLICY; IMPACT OF THE NEW-JERSEY ALL-PAYER R ATE-SETTING SYSTEM			
5371 1 4 6 4786 8 55 7 5 63 0 85	CYCLOSPORINE NEPHROTOXICITY; RENAL-TRANSPLANTATION IN BLACK RECIPIENTS; EARLY GRAFT FUNCTION; IMPACT OF RACE; ORGAN ALLOCATION			
5372 1 4 6 5043 3 47 16 3 100 0 88	ORGAN PROCUREMENT; NATIONAL-HEALTH CARE POLICY; CA DAVERIC RENAL-TRANSPLANTATION; DIABETIC NEPHROPATH			

C1
RANK
5519

5520

5521

5522

5523

5524

5525

5526

5527

5528

5529

5530

5531

SRT C4-C3-C2-C1, 1

M 1

SRT

Table 10

Major Countries Participating Above Expected Levels

C1	COUNTRY	OVER *	COUNTRY	OVER *	FIELD **	SHORT NAME
1398	Japan	3.4	England	1.8	B	endothelin
90	US	1.3	England	1.3	B	Alzheimer's disease
2726	US	2.1	Canada	1.3	B	national health insurance
1019	Japan	2.4	FRG	1.9	P	fusion reactor hydrogen plasma
41	Italy	2.0	FRG	1.6	P	boson
436	Japan	2.8	USSR	2.7	P	structure of oxide superconductors
623	FRG	2.4	England	1.8	B	gallstone endoscopy and lithotripsy
915	USSR	3.8	England	1.8	P	narrow quantum conductors
4068	US	1.7	FRG	1.3	P	ozone hole
1038	Canada	3.7	US	1.3	B	meta-analysis in medicine
1461	Italy	1.6	US	1.2	B	node-negative breast cancer
557	Italy	3.2	FRG	1.8	P	cold fusion
123	England	2.7	FRG	2.0	B	prostatic hyperplasia treatment
2	Italy	3.3	France	1.7	B	posttransfusion hepatitis
4726	England	6.5	Japan	3.3	P	erbium doped fiber laser
3291	Italy	2.3	US	1.9	B	cigarette smoking trends
868					P	Edgcombe earthquake modeling
4196	US	1.4	Italy	1.1	B	immunosuppressive agents
3403	FRG	3.1	Japan	2.1	P	homoaldol reactions & cage compounds
6894	Canada	7.0	England	2.6	B	cystic-fibrosis gene
8162	England	5.9	FRG	3.1	B	polymerase chain reaction & cancer
1185	Japan	1.3	US	1.2	P	supernova 1987A & strange matter
2269	Japan	9.2	Italy	2.2	P	the photon factory
3779	France	3.0	Japan	2.0	P	electron-microscopy of superconductors
5191	England	12.4			B	sexual behavior and HIV infection
8112	US	2.1	England	1.6	B	transplantation of viscera
450	France	2.4	England	2.0	B	antiphospholipid syndrome

* Number of times greater than expected for a country's participation.

** P = physical sciences; B = biomedical sciences

b. Fields Low in the U.S. and High in a Foreign Country

The assessment of national performance in science requires that there are targets or goals against which a country's research output can be compared. In the absence of such specific targets we can carry out comparative analyses using the performance of other nations which for some reason we may want to compare our performance. One reason is that we regard the country as a competitor in science-based fields or technology. Such is clearly now the case with Japan and by way of illustrating this approach to national comparisons, we have sought to identify areas in which Japan is stronger than expected and the US weaker than expected.

We again make use of the research front data base for 1989 and begin by counting the number of papers in each research front with author addresses from Japan, and a similar statistic for the US. From overall statistics we know that 42.9 percent of all papers in research fronts have US authors, and the comparable number for Japan is 6.8. Finding the difference between the actual country percentage for a given cluster and the expected value for that country gives the percentage points above or below expected. Since we want to determine those areas where Japan is above expected and the US is below expected the most, we add the amount Japan is above to the amount the US is below and sort on that parameter. Finally we limit the analysis to areas which have a minimum number of Japanese papers, which focuses our attention on areas where Japan has invested the most effort.

The results are given in Table 11. This table lists the 54 out of roughly 8,000 clusters in 1989 which have 15 percent or more Japanese papers and less than 35 percent US papers. We also require that the cluster contain at least 50 papers from Japan.

Analyzing this list in terms of broad subject matter, we find a preponderance of physical science areas (including physics and chemistry) over biomedical areas in the ratio of 34 to 20. Within physical sciences, physics outnumbers chemistry 22 to 12, and within physics, applied physics is very prominent having nearly the same number of research fronts as basic physics. In the biomedical sciences there is strong representation for pharmacology, plant sciences, and biotechnology, with an emphasis on natural products which have biological activity. Table 11 shows the broad field code in the column on the far right.

Another way to highlight the subject areas in which the high Japan/low US research fronts are concentrated is to arrange them in hierarchical order to show their nested structure. This is done in Table 12. The first areas are the isolates which have no higher level memberships. There are 15 of these out of the 54. We also show the percentage of core papers within the last three years on this table, a measure of the currency of the field. Any value of this percentage over 15 is higher than expected. Among

the isolates we recognize one area that appeared in our previous overall hot field list, namely the "the photon factory" (C1 2269). Other notable isolates are "sponge metabolites" (C1 63), a natural products area, and two semiconductor-related fields "surface melting" (C1 1003) and "molecular beam epitaxy" (C1 2212).

There are 14 research fronts at intermediate stages of isolation, namely the C2 and C3 levels. The most notable aggregation of high Japan/low US fields is C2 91 on, broadly speaking, electrical conductivity in organic materials, such as polymers, films and liquid crystals. Included in this grouping is the research effort in Japan to develop organic superconductors. These areas not particularly hot, but represent a long term research interest in Japan. Another interesting feature of the areas of intermediate isolation is the prevalence of biotechnology and natural products research. An example of a hot field in this category is on enzymatic catalysis in organic solvents (C1 507).

The remaining 25 research fronts on the Japan high/US low list are integrated into higher level clusters. The largest sub-grouping of these are the eight research fronts on high temperature superconductivity grouped into C3 #5. This group also contains the hottest research fronts, three having 100 percent immediacy. One of these fronts appeared on the list of hottest fields for the full database (C1 436). This is clearly an area where a Japanese advantage over the US could develop. Another major sub-grouping is in physics under C3 #6 which encompasses particle and nuclear physics and astrophysics. One hot area among these concerns the study of x-ray sources observed from the Japanese satellite called Ginga.

Another large grouping is C3 #15, dealing with transition metal and organometallic complexes and catalysis. These areas are also moderately hot. Three biomedical research fronts are grouped under C3 #8, including one of the hottest areas in the overall file, namely endothelin (C1 1398). Interestingly, the two other areas grouped with endothelin deal with other naturally occurring compounds with pharmaceutical potential, brain natriuretic peptide and atrial natriuretic peptide. The last and smallest grouping is also biomedical, C3 #89 on plant science and plant biotechnology. Finally, we note that the last research front listed on Table 12, C1 1019 on the Tokamak fusion reactor was also on our previous list of overall hot fields. Hence a total of four of the high Japan/low US fields were also on the list of hottest fields in the 1989 research front database. This is an indication of the forefront nature of Japan's research effort.

Table 11

1989 CLUSTERS STRONG IN JAPAN AND WEAK IN THE U.S.

Page 1

C1	CITING	CORE	JAPAN	US	NAME	FIELD
7342	34	2	74.2	4.1	BOARD GINGA; X-RAY TIME VARIATIONS; INTENSE IRON LINE EMISSION; QUASI-PERIODIC OSCILLATIONS	P
6581	28	3	82.0	13.4	STREPTOCOCCAL PREPARATION OK-432; NATURAL-KILLER ACTIVITY; AUTOIMMUNE KIDNEY-DISEASE	B
1962	46	10	74.0	7.8	HYDROLYZABLE TANNINS; ACTIVE CONSTITUENTS OF MEDICINAL-PLANTS; ANTIBACTERIAL SUBSTANCES IN JAPANESE GREEN TEA EXTRACT	B
3964	42	5	71.4	9.5	PINE CONE ANTITUMOR SUBSTANCES; PROTEIN-BOUND POLYSACCHARIDE; IMMUNOMODULATOR PSK; MURINE TUMORS; INHIBITION OF HERPES-SIMPLEX VIRUS-INFECTION	B
2269	41	7	62.6	8.4	PHOTON FACTORY; 53-POLE WIGGLER UNDULATOR BEAMLINE; SYNCHROTRON RADIATION; OPTICAL-CONSTANTS FOR COATED THIN-FILMS; REFLECTANCE SPECTRA OF IMPLANTED GAAS	P
182	52	5	70.5	18.8	ORGANOMETALLIC CHEMICAL VAPOR-DEPOSITION OF HIGH-TC SUPERCONDUCTING BI-SR-CA-CU-O FILMS; LASER ABLEATION; STRUCTURE FORMATION	P
2437	63	9	50.6	14.4	DECAY OF HYPERNUCLEI; K- ABSORPTION AT REST; SUPERCONDUCTING SPECTROMETER; SHELL-MODEL CALCULATION; HYPERON-NUCLEON SCATTERING	P
6393	144	8	49.2	13.0	BI-SR-CA-CU-O SYSTEM; HIGH-TC SUPERCONDUCTING PHASES; LOW-TEMPERATURE ELECTRON-MICROSCOPY; STRUCTURAL MODULATION; INCOMMENSURATE SUPERSTRUCTURE	P
7606	73	2	51.9	22.4	BRAIN NATRIURETIC PEPTIDE; ANESTHETIZED DOCA-SALT HYPERTENSIVE RATS; ALDOSTERONE SECRETION INHIBITORY FACTOR	B
765	85	9	34.9	18.2	THERMALLY STIMULATED DEPOLARIZATION CURRENT TECHNIQUE; SYNCHROTRON RADIATION; IMAGING PLATE; LUMINESCENCE EXCITATION OF BARIUM FLUOROHALIDES	P
1602	158	18	30.8	14.9	ASYMMETRIC HYDROGENATION; CHIRAL FERROCENYLPHOSPHINE TRANSITION-METAL COMPLEXES; ENANTIOSELECTIVE CATALYSIS	C
2104	221	15	40.9	25.4	FERMENTATION BROTH; TAXONOMY OF THE PRODUCING STRAIN; ANTITUMOR ANTIBIOTIC PHOSPHOLINE	B
2380	142	21	31.5	21.3	RADICAL CATIONS; INTRAMOLECULAR EXCIMER FORMATION; FLUORESCENCE SPECTROSCOPY; NANOSECOND LASER PHOTOLYSIS; DIASTEREOMERIC STYRENE TRIMERS	C

C1	CITING	CORE	JAPAN	US	NAME	FIELD
7623	246	2	28.0	19.3	CELLULASE IMMOBILIZATION; HYDROLYSIS OF CELLULOSE; ARTHROBACTER-GLOBIFORMIS I42; GLUCOSE IN EVERNIA-PRUNASTRI; SPRING WHEAT (TRITICUM-AESTIVUM L)	B
295	119	13	22.2	14.4	CERIUM HEAVY FERMION COMPOUNDS; KONDO SYSTEMS; METAMAGNETIC CERU2SI2; ANOMALOUS HALL-COEFFICIENT; HIGH MAGNETIC-FIELDS	P
2241	89	12	26.6	19.1	IGA NEPHROPATHY; SPONTANEOUS MESANGIAL GLOMERULONEPHRITIS OF DDY MICE; GLOMERULAR EXTRACELLULAR COMPONENTS	B
42	383	36	29.7	24.2	INCLUSION COMPLEXES; CYCLODEXTRIN COMPLEXATION; NITROXIDE RADICALS; MOLECULAR RECOGNITION; IONIC DETERGENTS; PHOTO-FRIES REARRANGEMENT	C
2642	217	8	26.2	21.3	PECTIC POLYSACCHARIDES; O-LINKED CARBOHYDRATE CHAINS; FAST ATOM BOMBARDMENT MASS-SPECTROMETRY; ANGELICA ACUTILOBA KITAGAWA; PLANT-CELL WALLS	B
346	132	25	23.5	21.2	SHAPE MEMORY ALLOYS; MARTENSITIC-TRANSFORMATION IN CU-ZN-AL; GROWTH VELOCITY	P
706	255	42	24.3	22.7	FERROELECTRIC LIQUID-CRYSTAL CELLS; INVESTIGATION OF SWITCHING BEHAVIOR; CHIRAL SMECTIC C-SMECTIC-A TRANSITION	P
4581	526	2	23.6	23.6	XANTHINE DEHYDROGENASE; PROTEIN ELECTROPHORESIS; INCUBATED BLOOD-CELL LYSATES; LIPOLYTIC ENZYMES	B
1915	274	34	16.9	17.2	PHASE-TRANSFER CATALYSIS; QUATERNARY CARBON CENTERS; GEMINAL VINYL DIAZIDES; UNSATURATED AZIDES; KETENE DITHIOACETALS; NUCLEOPHILIC REACTIVITY	C
2376	156	17	20.6	22.3	HAIRY ROOTS; TROPANE ALKALOIDS; RI PLASMID OF AGROBACTERIUM-RHIZOGENES; DIPLOID POTATO GENOTYPES; PUTRESCINE N-METHYLTRANSFERASE	B
507	442	53	16.9	18.8	LIPASE CATALYZED TRANSESTERIFICATIONS IN ORGANIC-SOLVENTS; HYDRATED REVERSED MICELLES; ENZYMIC CATALYSIS; IMMOBILIZED ENZYMES; ENANTIOMERIC PURITY	C
159	390	55	25.8	28.5	ORGANIC METAL; BEDT-TTF SALTS; WIDELY TUNABLE BAND FILLING; X-RAY CRYSTAL-STRUCTURE; PHthalocyanine SEMICONDUCTOR SENSORS	C
2751	127	3	30.5	34.1	AMINO-ACID SEQUENCE; PRIMARY STRUCTURE; ACTIVE-SITE CYSTEINE PEPTIDES	B

	CITING	CORE	JAPAN	US	NAME	FIELD
1	129	15	23.6	27.3	MICRONUCLEUS TEST; ORAL GAVAGE; INTRAPERITONEAL INJECTION	B
3	218	17	18.6	24.4	HIGH-TC SUPERCONDUCTOR YBA ₂ CU ₃ O ₇ -DELTA; DOPANT SUBSTITUTION; ORTHORHOMBIC YBA ₂ (Cu ₁ -XFEX) ₃ O ₇ ; TETRAGONAL PHASES; ELECTRIC-FIELD GRADIENTS	P
3	335	27	21.6	28.0	ASYMMETRIC OXIDATION; SHARPLESS KINETIC RESOLUTION; EPOXY ALCOHOLS; BETA-KETO SULFOXIDES; TRANSITION-METAL COMPLEXES	C
4	236	33	16.2	23.9	PYRROLOQUINOLINE QUINONE; IMMOBILIZED HYBRIDOMA CELLS; COENZYME PQQ; ALGINATE GEL BEADS; QUINOPROTEIN METHYLAMINE DEHYDROGENASE	B
7	208	22	23.1	30.9	ORGANOCOPPER REAGENTS; HIGHER-ORDER CYANOCUPRATE S; DOUBLE MICHAEL ADDITION; COPPER CHEMISTRY	C
0	139	18	17.4	25.4	LOW-MASS X-RAY BINARIES; LUMINOSITY DEPENDENCE OF THE PULSE PROFILE; HIGH-ENERGY SHOWERS	P
5	2055	59	21.7	30.7	HIGH-TC SUPERCONDUCTORS; MIXED-VALENCE COPPER OXIDES; 110 K PHASE IN PB-SUBSTITUTED BI-SR-CA-CU-O	P
1	415	51	16.7	26.3	QUARTZ CRYSTAL MICROBALANCE; ELECTROCHEMICAL INVESTIGATIONS OF ELECTRONICALLY CONDUCTIVE POLYMERS; CHARGE-TRANSPORT RATES IN POLYPYRROLE	C
3	392	42	19.9	29.6	SPONGE SECONDARY METABOLITES; MARINE NATURAL-PRODUCTS; AUSTRALIAN SOFT CORALS; TETRAHYDROPYRAN SYSTEMS; POLYKETIDE ANTIBIOTIC BIOSYNTHESIS	B
4	286	30	22.4	32.2	PALLADIUM-CATALYZED CROSS COUPLING; VINYL TRIFLATES; ALKENYL HALIDES	C
2	192	25	24.7	34.9	MOLECULAR-BEAM EPITAXY; METALORGANIC CHEMICAL VAPOR-DEPOSITION; (110) GAAS SUBSTRATES; ORDERED SEMICONDUCTORS; BAND-GAP ENERGY	P
3	587	37	23.5	34.0	ENDOTHELIN STIMULATES RELEASE; RAT CARDIAC MEMBRANES; VASCULAR SMOOTH-MUSCLE; SYSTEMIC VASOCONSTRICTOR PEPTIDE	B
5	448	46	16.9	27.6	MIXED ANIONIC NONIONIC SURFACTANT MICELLES; DEIONIZED COLLOIDAL SPHERES; RODLIKE POLYMERS; CHLORHEXIDINE DIGLUCONATE; DEBYE-SCREENING LENGTH	C

C1	CITING	CORE	JAPAN	US	NAME	FIELD
289	464	55	19.4	32.2	SMALL HEPATOCELLULAR-CARCINOMA; HEPATIC RESECTIO N; TRANSCATHETER ARTERIAL CHEMOTHERAPY; LIVER SU RGERY; PREOPERATIVE CHEMOEMBOLIZATION THERAPY	B
2857	281	8	15.0	28.4	CALCIUM CHANNELS IN VASCULAR SMOOTH-MUSCLE; RAT AORTA; CA-2+ ANTAGONISTS; RABBIT MESENTERIC RESI STANCE VESSELS; K+-INDUCED CONTRACTIONS	B
1539	352	17	18.8	32.4	ASPARAGINE-LINKED OLIGOSACCHARIDES; SUGAR CHAINS ; ENDOGENOUS RECEPTORS FOR NEOGLYCOPROTEINS; LEC TIN HISTOCHEMISTRY; MULTINUCLEATE GIANT-CELLS	B
2371	318	41	15.2	29.1	MAGNETIC SURFACE ANISOTROPY OF TRANSITION-METAL ULTRATHIN FILMS; FERROMAGNETIC MONOLAYER FE(110) ; VOLUME INSTABILITIES; BULK ALLOYS	P
1019	233	36	16.0	30.1	HYDROGEN TRANSPORT; TOKAMAK FUSION TEST REACTOR; HIGH-FLUX PLASMA BOMBARDMENT; CARBON WALLS; IMP URITY PRODUCTION AT GRAPHITE LIMITERS; EROSION B EHAVIOR	P
5636	367	12	17.3	31.6	BACTERIAL LIPOPOLYSACCHARIDE; LIPID-A COMPONENT; STRUCTURAL REQUIREMENTS; MURINE MONOCLONAL-ANTI BODIES; PARTIAL STIMULATION; IMMUNOCHEMICAL SPEC IFICITY	B
436	605	27	19.3	33.7	HIGH-TC SUPERCONDUCTORS; SINGLE-CRYSTAL LA2CUO4; MIXED-VALENCE COPPER OXIDES	P
3101	406	33	18.1	32.7	SOLUBLE ELECTRICALLY CONDUCTING POLYMERS; ALTERN ATING TRANS-POLYACETYLENE; DOPED POLY(3-ALKYLTHI OPHENES); ALKYL CHAIN-LENGTH	P
152	361	38	16.7	31.4	NON-LINEAR EXCITATIONS IN ISING-TYPE MAGNETIC CH AIN SYSTEMS; PURE BIQUADRATIC EXCHANGE; QUANTUM FLUCTUATIONS	P
456	132	8	19.1	35.0	SUPERSYMMETRIC DARK MATTER; SUSY MODELS; HIGGS B OSONS; RADIATIVE NEUTRALINO DECAY; E+E- ANNIHILA TION; LEPTON NUMBER NONCONSERVATION; LIGHT PHOTI NOS	P
1003	275	31	17.1	33.3	SURFACE MELTING; WETTING BEHAVIOR OF SOLID ADSOR BED FILMS; INTERFACIAL ATOMIC STEPS DURING SILIC ON OXIDATION	P
916	597	39	16.6	32.9	HIGH-TC SUPERCONDUCTORS; LOW-FIELD MICROWAVE-ABS ORPTION; THERMALLY ACTIVATED FLUX CREEP; YBA2CU3 O7-DELTA SINGLE-CRYSTAL	P
770	244	33	15.0	31.8	HYDROGENATED AMORPHOUS-SILICON; OPTICAL DEGRADAT ION IN A-SI-H FILMS; ENERGY-RESOLVED DEFECT KINE TICS	P

C1	CITING	CORE	JAPAN	US	NAME	FIELD
1023	270	30	16.4	34.2	METAL HYDRIDE REDUCTIONS; ORGANOCOPPER REAGENTS; DIASTEREOFACIAL SELECTIVITY; ELECTRONIC CONTROL OF STEREOSELECTIVITY; DIELS-ALDER ADDITION; CHI RAL CENTER	C
887	804	48	15.0	33.7	ATRIAL NATRIURETIC PEPTIDE; CHRONIC LEFT-SIDED H EART-FAILURE; NACL-RESISTANT SPONTANEOUSLY HYPER TENSIVE RATS	B

Table 12

High Japan/Low US Clusters Arranged in Hierarchical Order

Page 1

C4	C3	C2	C1	IMMPR	NAME
0	0	0	63	24	SPONGE SECONDARY METABOLITES; MARINE NATURAL-PRODUCTS; AUSTRALIAN SOFT CORALS; TETRAHYDROPYRAN SYSTEMS; POLYKETIDE ANTIBIOTIC BIOSYNTHESIS
0	0	0	152	8	NON-LINEAR EXCITATIONS IN ISING-TYPE MAGNETIC CHAIN SYSTEMS; PURE BIQUADRATIC EXCHANGE; QUANTUM FLUCTUATIONS
0	0	0	346	8	SHAPE MEMORY ALLOYS; MARTENSITIC-TRANSFORMATION IN CU-ZN-AL; GROWTH VELOCITY
0	0	0	765	11	THERMALLY STIMULATED DEPOLARIZATION CURRENT TECHNIQUE; SYNCHROTRON RADIATION; IMAGING PLATE; LUMINESCENCE EXCITATION OF BARIUM FLUOROHALIDES
0	0	0	1003	29	SURFACE MELTING; WETTING BEHAVIOR OF SOLID ADSORBED FILMS; INTERFACIAL ATOMIC STEPS DURING SILICON OXIDATION
0	0	0	1023	3	METAL HYDRIDE REDUCTIONS; ORGANOCOPPER REAGENTS; DIASTEREOFACIAL SELECTIVITY; ELECTRONIC CONTROL OF STEREOSELECTIVITY; DIELS-ALDER ADDITION; CHIRAL CENTER
0	0	0	1915	3	PHASE-TRANSFER CATALYSIS; QUATERNARY CARBON CENTERS; GEMINAL VINYL DIAZIDES; UNSATURATED AZIDES; KETENE DITHIOACETALS; NUCLEOPHILIC REACTIVITY
0	0	0	2212	32	MOLECULAR-BEAM EPITAXY; METALORGANIC CHEMICAL VAPOR-DEPOSITION; (110) GAAS SUBSTRATES; ORDERED SEMICONDUCTORS; BAND-GAP ENERGY
0	0	0	2269	43	PHOTON FACTORY; 53-POLE WIGGLER UNDULATOR BEAMLINE; SYNCHROTRON RADIATION; OPTICAL-CONSTANTS FOR COATED THIN-FILMS; REFLECTANCE SPECTRA OF IMPLANTED GAAS
0	0	0	2380	5	RADICAL CATIONS; INTRAMOLECULAR EXCIMER FORMATION; FLUORESCENCE SPECTROSCOPY; NANOSECOND LASER PHOTOLYSIS; DIASTEREOMERIC STYRENE TRIMERS
0	0	0	2751	0	AMINO-ACID SEQUENCE; PRIMARY STRUCTURE; ACTIVE-SITE CYSTEINE PEPTIDES
0	0	0	2857	13	CALCIUM CHANNELS IN VASCULAR SMOOTH-MUSCLE; RAT AORTA; CA-2+ ANTAGONISTS; RABBIT MESENTERIC RESISTANCE VESSELS; K+-INDUCED CONTRACTIONS
0	0	0	3964	0	PINE CONE ANTITUMOR SUBSTANCES; PROTEIN-BOUND POLYSACCHARIDE; IMMUNOMODULATOR PSK; MURINE TUMORS; INHIBITION OF HERPES-SIMPLEX VIRUS-INFECTION

C3	C2	C1	IMMPR NAME
0	0	4581	0 XANTHINE DEHYDROGENASE; PROTEIN ELECTROPHORESIS; INCUBATED BLOOD-CELL LYSATES; LIPOLYTIC ENZYMES
0	0	6581	0 STREPTOCOCCAL PREPARATION OK-432; NATURAL-KILLER ACTIVITY; AUTOIMMUNE KIDNEY-DISEASE
0	27	42	14 INCLUSION COMPLEXES; CYCLODEXTRIN COMPLEXATION; NITROXIDE RADICALS; MOLECULAR RECOGNITION; IONIC DETERGENTS; PHOTO-FRIES REARRANGEMENT
0	28	289	5 SMALL HEPATOCELLULAR-CARCINOMA; HEPATIC RESECTION; TRANSCATHETER ARTERIAL CHEMOTHERAPY; LIVER SURGERY; PREOPERATIVE CHEMOEMBOLIZATION THERAPY
0	40	770	27 HYDROGENATED AMORPHOUS-SILICON; OPTICAL DEGRADATION IN A-SI-H FILMS; ENERGY-RESOLVED DEFECT KINETICS
0	91	159	15 ORGANIC METAL; BEDT-TTF SALTS; WIDELY TUNABLE BAND FILLING; X-RAY CRYSTAL-STRUCTURE; PHTHALOCYANINE SEMICONDUCTOR SENSORS
0	91	511	10 QUARTZ CRYSTAL MICROBALANCE; ELECTROCHEMICAL INVESTIGATIONS OF ELECTRONICALLY CONDUCTIVE POLYMERS; CHARGE-TRANSPORT RATES IN POLYPYRROLE
0	91	706	17 FERROELECTRIC LIQUID-CRYSTAL CELLS; INVESTIGATION OF SWITCHING BEHAVIOR; CHIRAL SMECTIC C-SMECTIC-A TRANSITION
0	91	3101	27 SOLUBLE ELECTRICALLY CONDUCTING POLYMERS; ALTERNATING TRANS-POLYACETYLENE; DOPED POLY(3-ALKYLTHIOPHENES); ALKYL CHAIN-LENGTH
0	105	184	12 PYRROLOQUINOLINE QUINONE; IMMOBILIZED HYBRIDOMA CELLS; COENZYME PQQ; ALGINATE GEL BEADS; QUINOPROTEIN METHYLAMINE DEHYDROGENASE
0	246	507	23 LIPASE CATALYZED TRANSESTERIFICATIONS IN ORGANIC-SOLVENTS; HYDRATED REVERSED MICELLES; ENZYMATIC CATALYSIS; IMMOBILIZED ENZYMES; ENANTIOMERIC PURITY
0	311	2241	25 IGA NEPHROPATHY; SPONTANEOUS MESANGIAL GLOMERULONEPHRITIS OF DDY MICE; GLOMERULAR EXTRACELLULAR COMPONENTS
0	482	1539	24 ASPARAGINE-LINKED OLIGOSACCHARIDES; SUGAR CHAINS; ENDOGENOUS RECEPTORS FOR NEOGLYCOPROTEINS; LECTIN HISTOCHEMISTRY; MULTINUCLEATE GIANT-CELLS

C4	C3	C2	C1	IMMPR NAME
0	0	656	7623	0 CELLULASE IMMOBILIZATION; HYDROLYSIS OF CELLULOSE; ARTHROBACTER-GLOBIFORMIS I42; GLUCOSE IN EVERNIA-PRUNASTRI; SPRING WHEAT (TRITICUM-AESTIVUM L)
0	10	516	2104	0 FERMENTATION BROTH; TAXONOMY OF THE PRODUCING STRAIN; ANTITUMOR ANTIBIOTIC PHOSPHOLINE
0	59	622	1962	20 HYDROLYZABLE TANNINS; ACTIVE CONSTITUENTS OF MEDICINAL-PLANTS; ANTIBACTERIAL SUBSTANCES IN JAPANESE GREEN TEA EXTRACT
1	2	24	2376	18 HAIRY ROOTS; TROPANE ALKALOIDS; RI PLASMID OF AGROBACTERIUM-RHIZOGENES; DIPLOID POTATO GENOTYPES; PUTRESCINE N-METHYLTRANSFERASE
1	5	69	2371	39 MAGNETIC SURFACE ANISOTROPY OF TRANSITION-METAL ULTRATHIN FILMS; FERROMAGNETIC MONOLAYER Fe(110); VOLUME INSTABILITIES; BULK ALLOYS
1	5	102	182	100 ORGANOMETALLIC CHEMICAL VAPOR-DEPOSITION OF HIGH-TC SUPERCONDUCTING Bi-SR-Ca-Cu-O FILMS; LASER ABLATION; STRUCTURE FORMATION
1	5	102	435	98 HIGH-TC SUPERCONDUCTORS; MIXED-VALENCE COPPER OXIDES; 110 K PHASE IN Pb-SUBSTITUTED Bi-SR-Ca-Cu-O
1	5	102	436	63 HIGH-TC SUPERCONDUCTORS; SINGLE-CRYSTAL La2CuO4; MIXED-VALENCE COPPER OXIDES
1	5	102	916	77 HIGH-TC SUPERCONDUCTORS; LOW-FIELD MICROWAVE-ABSORPTION; THERMALLY ACTIVATED FLUX CREEP; YBa2Cu3O7-DELTA SINGLE-CRYSTAL
1	5	102	1063	100 HIGH-TC SUPERCONDUCTOR YBa2Cu3O7-DELTA; DOPANT SUBSTITUTION; ORTHORHOMBIC YBa2(Cu1-XPbX)3OY; TETRAGONAL PHASES; ELECTRIC-FIELD GRADIENTS
1	5	102	6393	100 Bi-SR-Ca-Cu-O SYSTEM; HIGH-TC SUPERCONDUCTING PHASES; LOW-TEMPERATURE ELECTRON-MICROSCOPY; STRUCTURAL MODULATION; INCOMMENSURATE SUPERSTRUCTURE
1	5	161	295	38 CERIUM HEAVY FERMION COMPOUNDS; KONDO SYSTEMS; METAMAGNETIC CeRu2Si2; ANOMALOUS HALL-COEFFICIENT; HIGH MAGNETIC-FIELDS
1	6	17	456	25 SUPERSYMMETRIC DARK MATTER; SUSY MODELS; HIGGS BOSONS; RADIATIVE NEUTRALINO DECAY; E+E- ANNIHILATION; LEPTON NUMBER NONCONSERVATION; LIGHT PHOTINOS

C4	C3	C2	C1	IMMPR NAME
1	6	17 2437	22	DECAY OF HYPERNUCLEI; K- ABSORPTION AT REST; SUPERCONDUCTING SPECTROMETER; SHELL-MODEL CALCULATION; HYPERON-NUCLEON SCATTERING
1	6	112 1410	17	LOW-MASS X-RAY BINARIES; LUMINOSITY DEPENDENCE OF THE PULSE PROFILE; HIGH-ENERGY SHOWERS
1	6	112 7342	100	BOARD GINGA; X-RAY TIME VARIATIONS; INTENSE IRON LINE EMISSION; QUASI-PERIODIC OSCILLATIONS
1	8	12 1398	76	ENDOTHELIN STIMULATES RELEASE; RAT CARDIAC MEMBRANES; VASCULAR SMOOTH-MUSCLE; SYSTEMIC VASOCONSTRICTOR PEPTIDE
1	8	363 887	4	ATRIAL NATRIURETIC PEPTIDE; CHRONIC LEFT-SIDED HEART-FAILURE; NAOL-RESISTANT SPONTANEOUSLY HYPERTENSIVE RATS
1	8	363 7606	50	BRAIN NATRIURETIC PEPTIDE; ANESTHETIZED DOCA-SALT HYPERTENSIVE RATS; ALDOSTERONE SECRETION INHIBITORY FACTOR
1	15	43 64	23	PALLADIUM-CATALYZED CROSS COUPLING; VINYL TRIFLUORIDES; ALKENYL HALIDES
1	15	136 1602	33	ASYMMETRIC HYDROGENATION; CHIRAL FERROCENYLPHOSPHINE TRANSITION-METAL COMPLEXES; ENANTIOSELECTIVE CATALYSIS
1	15	257 537	27	ORGANOCOPPER REAGENTS; HIGHER-ORDER CYANOCOPPERATES; DOUBLE MICHAEL ADDITION; COPPER CHEMISTRY
1	15	777 2743	19	ASYMMETRIC OXIDATION; SHARPLESS KINETIC RESOLUTION; EPOXY ALCOHOLS; BETA-KETO SULFOXIDES; TRANSITION-METAL COMPLEXES
1	25	305 946	9	MIXED ANIONIC NONIONIC SURFACTANT MICELLES; DEIONIZED COLLOIDAL SPHERES; RODLIKE POLYMERS; CHLORHEXIDINE DIGLUCONATE; DEBYE-SCREENING LENGTH
1	52	327 3703	7	MICRONUCLEUS TEST; ORAL GAVAGE; INTRAPERITONEAL INJECTION
1	89	392 2642	0	PECTIC POLYSACCHARIDES; O-LINKED CARBOHYDRATE CHAINS; FAST ATOM BOMBARDMENT MASS-SPECTROMETRY; ANGELICA ACUTILOBA KITAGAWA; PLANT-CELL WALLS

C4	C3	C2	C1	IMMPR NAME	
1	89	392 5636	8	BACTERIAL LIPOPOLYSACCHARIDE; LIPID-A COMPONENT; STRUCTURAL REQUIREMENTS; MURINE MONOCLONAL-ANTI BODIES; PARTIAL STIMULATION; IMMUNOCHEMICAL SPECIFICITY	
4	87	308 1019	58	HYDROGEN TRANSPORT; TOKAMAK FUSION TEST REACTOR; HIGH-FLUX PLASMA BOMBARDMENT; CARBON WALLS; IMPURITY PRODUCTION AT GRAPHITE LIMITERS; EROSION BEHAVIOR	

c. Measuring Performance of Research Sectors

In the previous two sections we explored the use of research fronts, aggregations of scientific papers on specific topics which have been generated by an algorithmic procedure. As noted previously, one of the ways to devise new science indicators, is to aggregate scientific papers in new ways. In the Task 1 we used the individual academic institution as the basis for grouping papers. In this section we will experiment with an extension of the institutional approach, that is, using sets of related institutions to construct indicators for the performance of larger segments of the research enterprise. This effort should be seen as another way of classifying or aggregating the scientific literature into scientifically or socially relevant categories which can be subject to bibliometric analysis.

The kinds of institutional groupings which might have policy relevance range from types of academic institutions (e.g. private institutions versus public, undergraduate versus graduate, etc.), independent research labs versus Federal research labs, and groupings of commercial organizations representing industrial sectors. We have drawn primarily on the commercial organizations in this section to illustrate this approach because little prior attention has been given to the scientific performance of these organizations due in part to the assumption that scientists who work in industry publish less and their research has less impact than their academic counterparts. Our final example is from the government sector and tracks the performance of a group of Federal research labs.

The methodology used in the following case studies is similar to that used in the analysis of individual academic organizations reported under Task 1. We use the ISI Science Indicators file and extract all cited articles from the set of institutions which we selected to represent the particular sector. The procedure for computing the aggregate citation counts and citation impacts is the same as for individual institutions. In effect we count them as if all the articles from the different institutions were coming from a single source. Hence, there is no weighting of items from different institutions. Again, the mean citations per cited article (citation impact) is used as the statistical measure and this is plotted as before in eight-year sliding windows. What follows is a brief description of each of the institutional sets in terms of their citation impact curve and most cited paper listing.

1. Biotechnology Companies

Twelve of the largest biotechnology companies in terms of number of employees were identified using a standard source book for the field (7). The plot of citation impact (Figure 20) shows a continuously rising pattern throughout the period 1973 to 1988. This is the most dramatic growth in citation impact that we observed to date, and defines a successful science-based technol-

ogy, at least in terms of its bibliometric profile. Examination of the 100 most cited papers from this group of organizations reveals the reason for the dramatic increase: 92 percent of the papers were written in the eight year period 1981-1988, and only eight are from the earlier eight year period 1973-1980. This is the highest degree of currency which we have observed. A subject analysis of the most cited papers is beyond the scope of this report, but not unexpectedly all deal in some way with DNA and gene products.

2. Pharmaceutical Companies

Nine of the largest international drug companies were selected for this analysis. They were selected for having the largest numbers of papers and the highest 16 year citation impacts in ISI Science Indicators file. The plot shows a generally high citation impact (Figure 21), but a declining one in recent years. Note that the scale of the citation impact plot has been reduced to show this and subsequent cases. Interestingly, an analysis of the 100 most cited papers reveals a situation directly opposite to the case of the biotechnology companies: 91 percent of these papers are from the earlier eight year period, and only nine percent are from the current eight year period. This means that the corpus of most important work is aging for these companies, and possibly also their personnel base.

3. Chemical Companies

Five U.S. chemical companies were selected. These were the top five companies ranked by sales and categorized as chemical companies by Fortune magazine (8). The citation impact curve (Figure 22) is generally lower than for pharmaceuticals, but unlike that previous case, the chemical companies are on a rising impact curve, after a slight dip in the late 1970s. When we categorize the most cited papers we see some perhaps significant shifts. The number of recent (1981-1988) highly cited papers is high, namely 39 percent, and there has been a shift away from chemistry topics to biomedicine as well as physics. Biomedical papers account for only 28 percent of the early most cited papers, while in the recent period they account for 77 percent of the most cited papers. Physics also increases from 3 percent to 13 percent. We conclude that either the nature of the companies or the nature of chemistry is changing.

4. Electronics and Computer Companies

The set of six U.S. companies analyzed here were selected by taking the top two companies by sales from each of three categories in the Fortune list. The categories were: Computers, Electronics, and Scientific/Photographic Equipment. While not completely homogeneous, we might consider this a physical science-based group. The citation impact curve (Figure 23) shows a gradually rising pattern over the 16 year period, at a slightly higher level than the previous chemical company group. The number of recent highly cited papers of 19 percent is not as

striking for this group as for the chemical group, and there are no major subject shifts evident: physics papers constitute about 80 percent and chemistry about 20 percent in both early and recent periods. Thus, the cause for increases in impact must be sought within these continuing subject areas.

5. Fortune 500 Top 20 Companies

For this sample of organizations we simply selected the top 20 companies in terms of 1989 sales in the Fortune 500 listing. This is a mixed group consisting of automotive, aerospace, oil, electronics, chemical, food and soap companies. The citation impact curve (Figure 24) shows a gradual climb after a small dip in the late 1970s. There is in addition a substantial number of recent highly cited papers, namely 26 percent. The subject trends are similar to what we have observed before. There is a shift toward biomedicine for the recent papers (8 percent in the earlier period to 35 percent in the recent period) and toward physics (45 percent in the earlier period to 61 percent in the recent period). Again, chemistry, at least in its traditional form, is less evident in the most cited paper-set for these companies. New forms of physics, including work on high temperature superconductivity and semiconductor materials, and new forms of biomedicine, particularly biotechnology, are fueling the increase in impact.

6. National Laboratories

Our non-corporate case is a set of eight national laboratories administered by the Department of Energy. There is no significant movement in their citation impact curve over the 16 year period (see Figure 25). There has been, however, an interesting shift in the subject mix of the most cited papers. Twenty percent of the 100 most cited papers are from the recent period (1981-1988). The striking shift is that in the earlier period (1973-1980) 32 percent of the highly cited papers were biomedical, while in the current period only 10 percent are in this field, in contrast to most of our previous cases which show a shift toward biomedical work. At the same time there has been an increase in physics related papers from 57 percent in the early period to 80 percent in the recent period. Throughout, chemistry has remained steady at 10 percent. The shift away from biomedicine and toward physics may be the result of policy shifts at DOE.

Figure 20

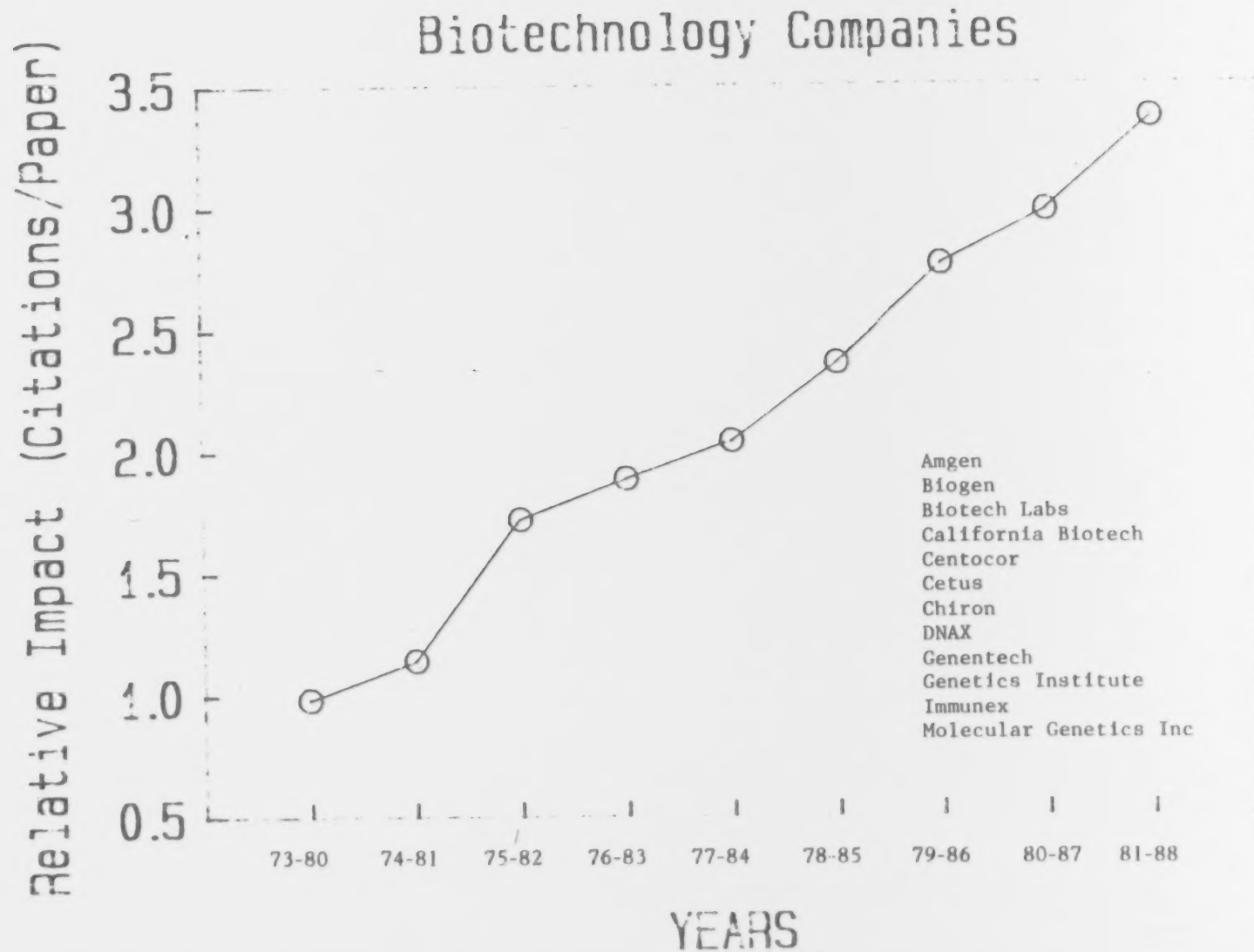


Table 21

Pharmaceutical Companies

Relative Impact (Citations/Paper)

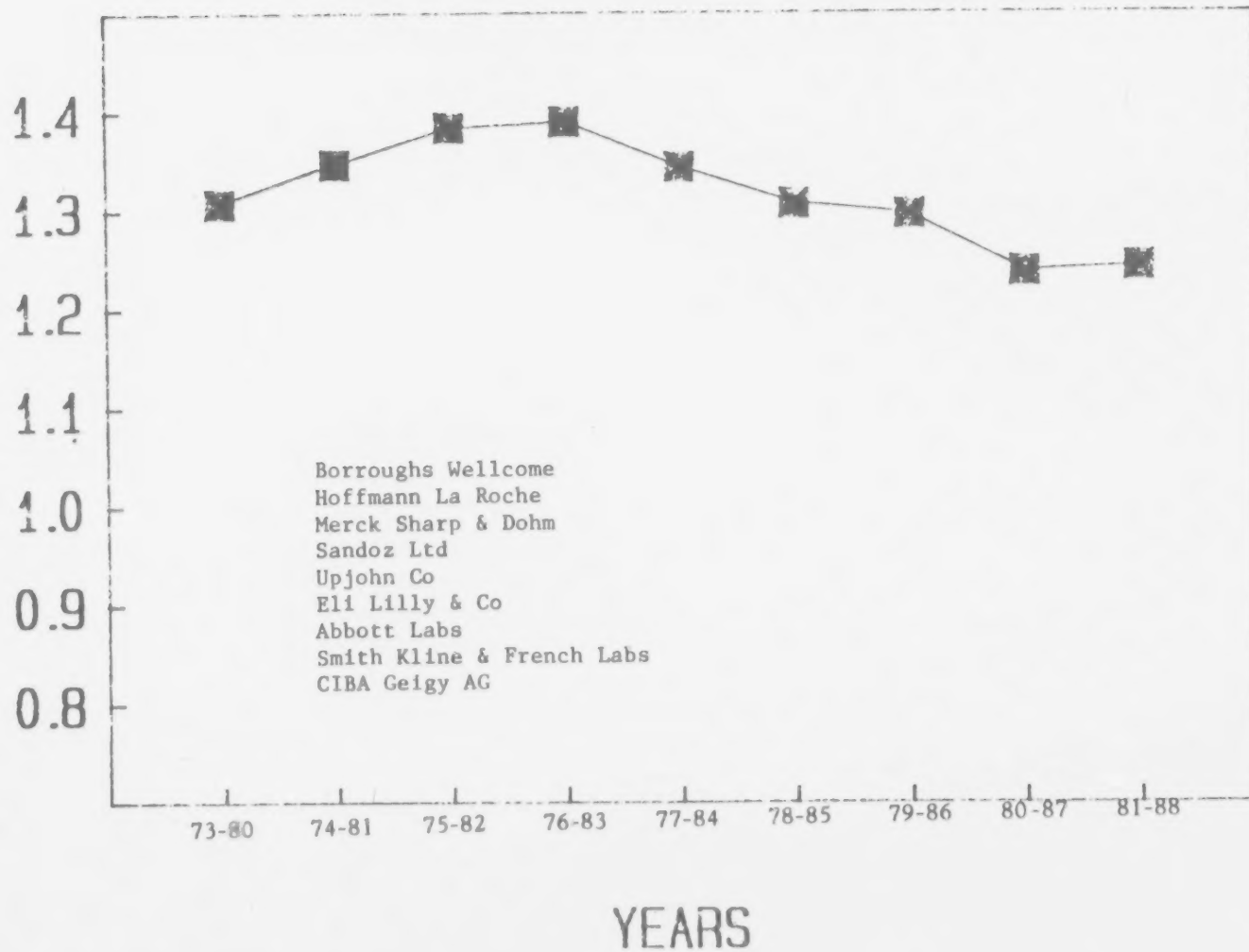


Table 22

Chemical Companies

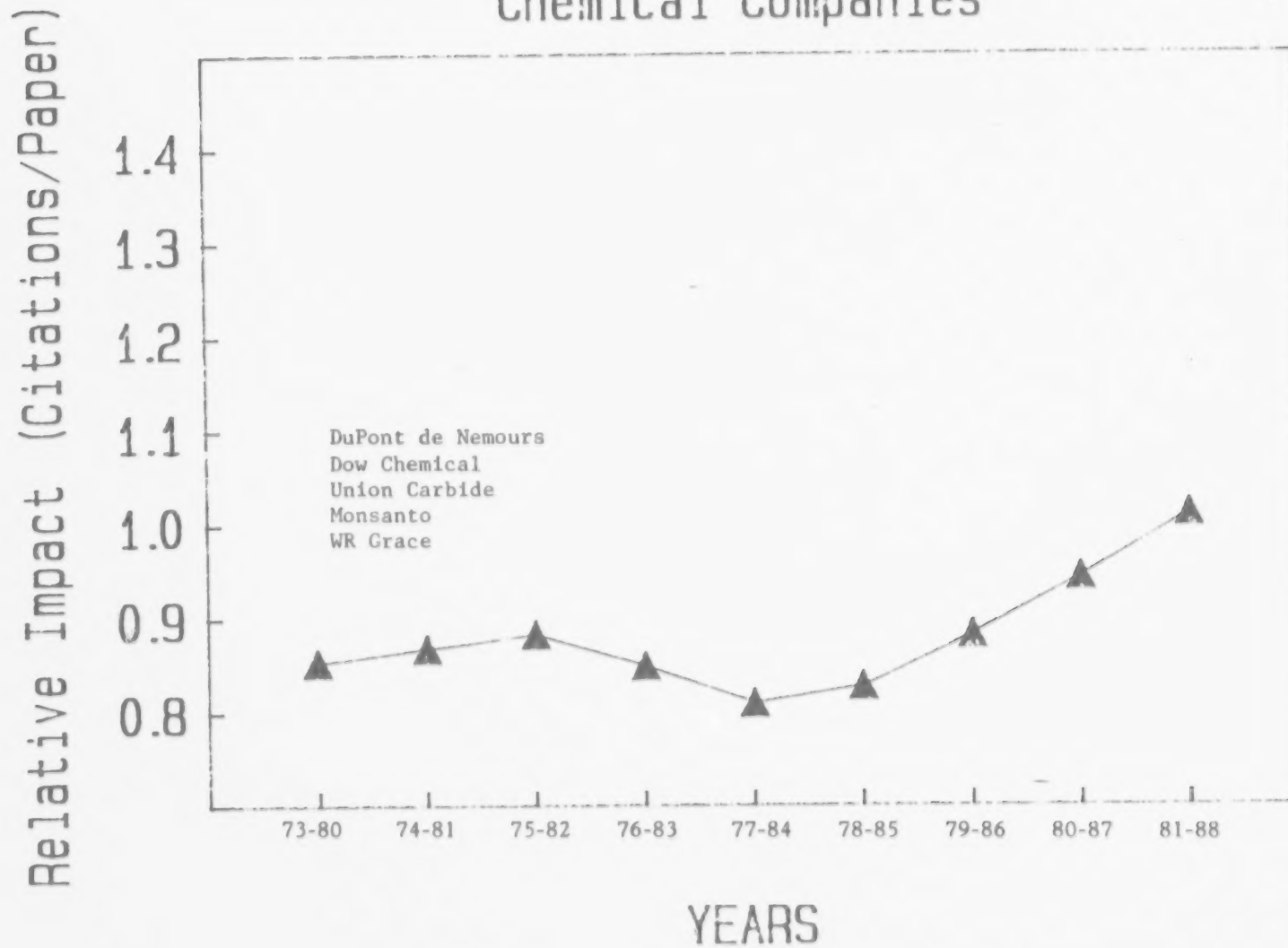


Table 23

Electronics & Computer Companies

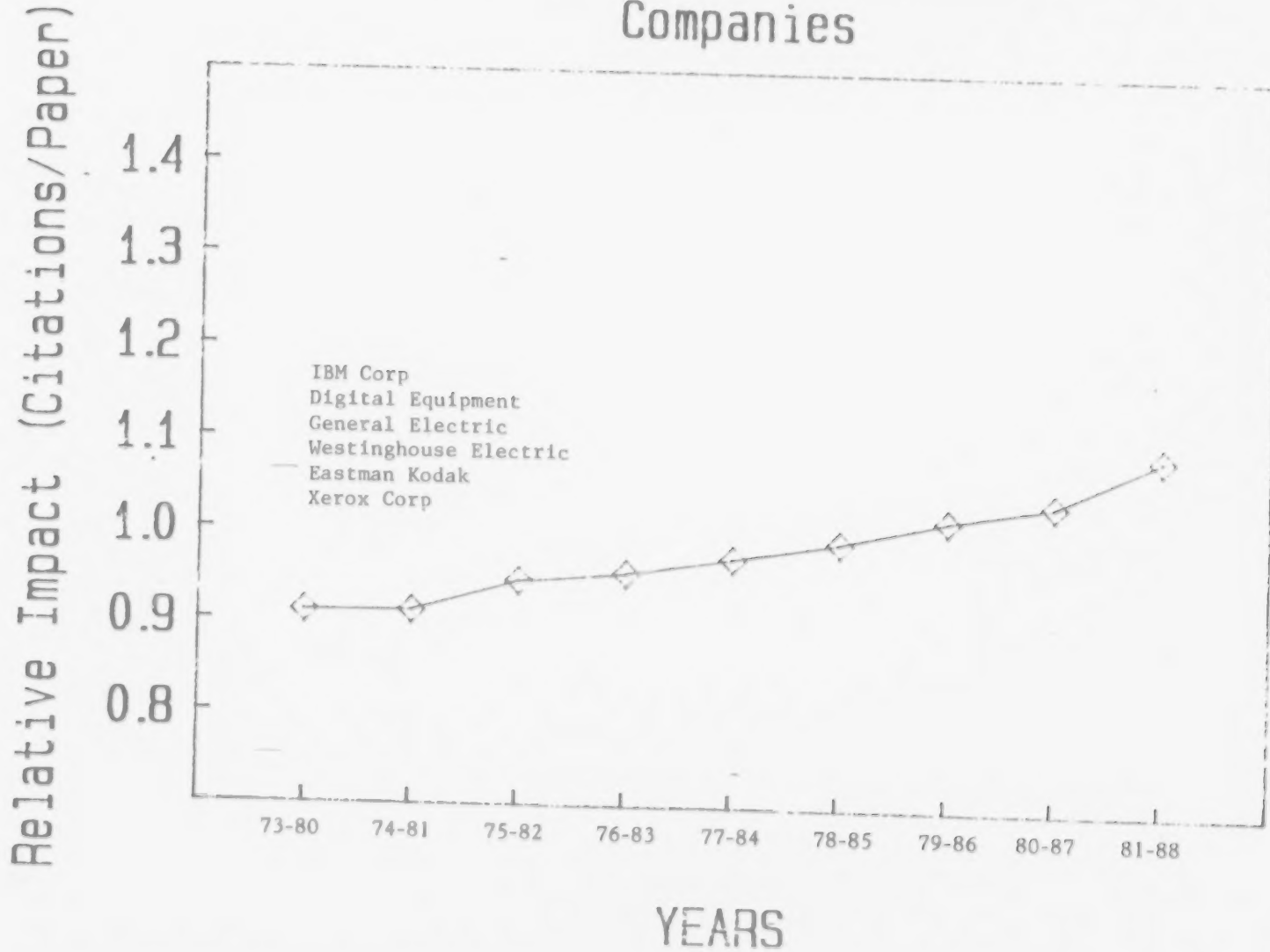


Figure 24

Fortune 500 Top 20

Relative Impact (Citations/Paper)

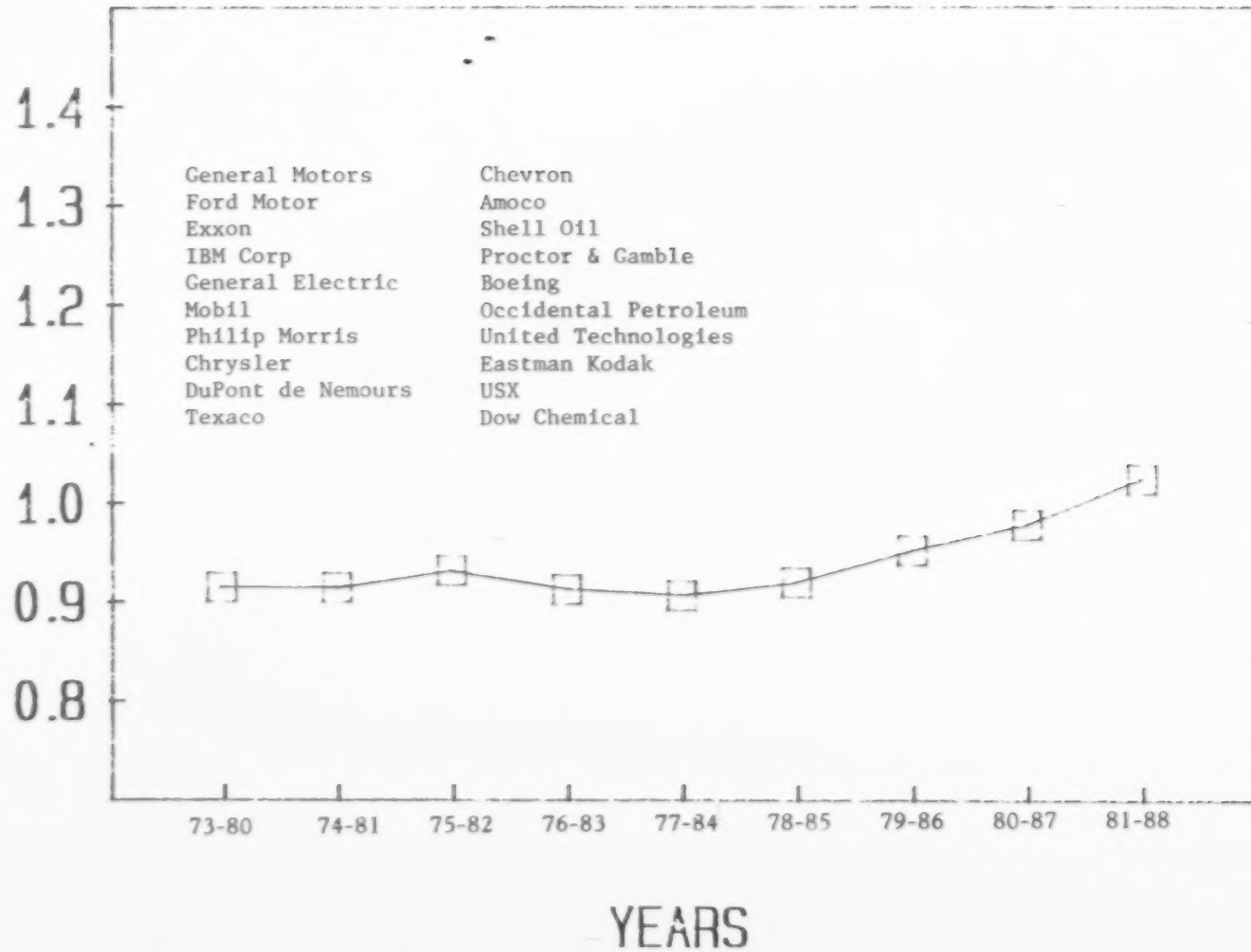
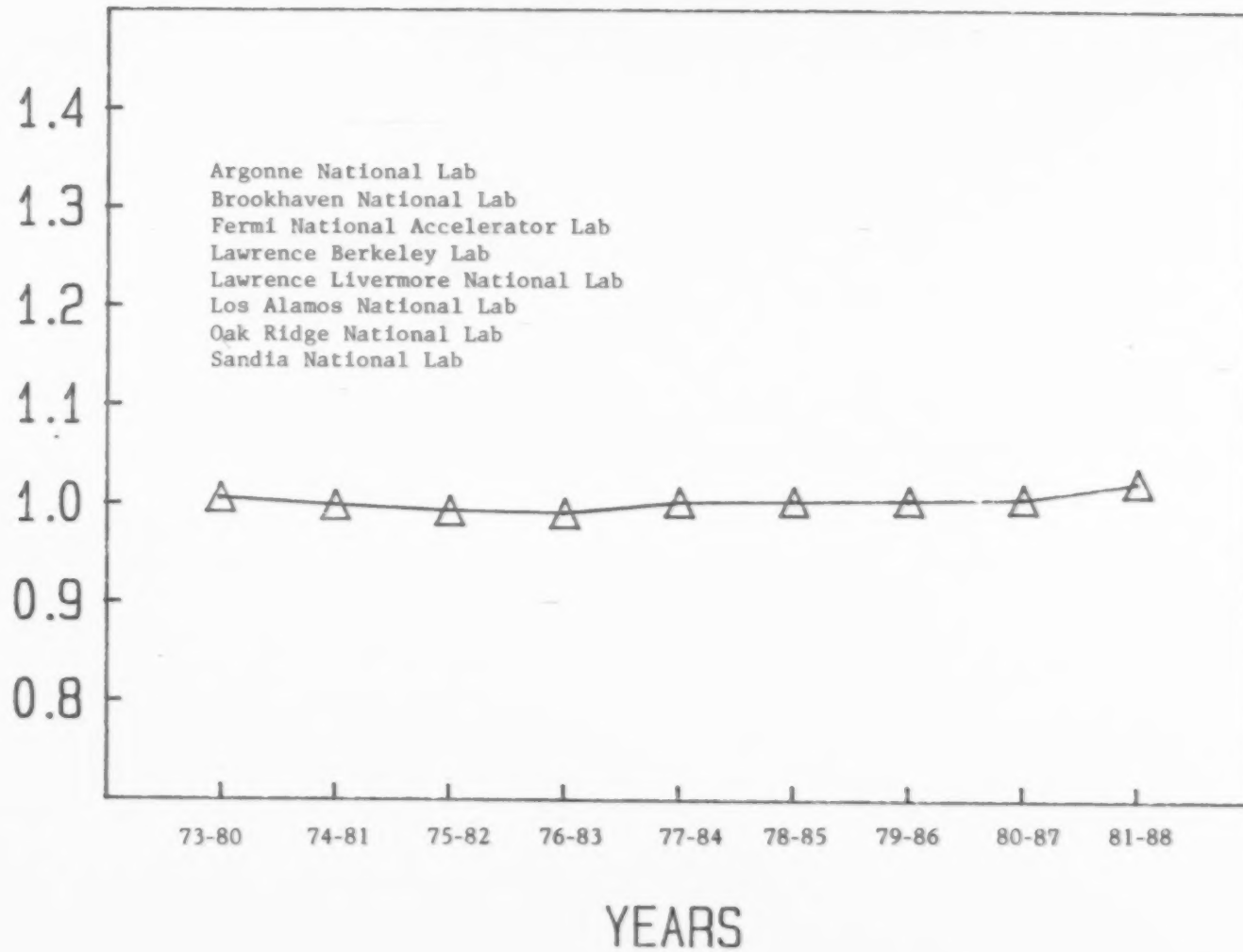


Figure 25

NATIONAL LABORATORIES

RELATIVE IMPACT (CITATIONS/PAPER)



d. Discussion of Task 3

We have argued that many new bibliometric indicators can be developed by using different methods of aggregating scientific papers. We have explored the use of a co-citation based clustering of scientific papers as one approach to creating new indicators of the currency of research areas ("hot fields") and the comparative study of national research strengths (low US/high Japanese fields). The advantage of using an algorithmic approach to defining fields is that our presuppositions about how science is structured or organized do not enter the picture. One disadvantage is that the areas we obtain are perhaps too fine grained and call for aggregation at a higher level. This however is also easily accomplished by a second iteration of clustering.

It is clear that co-citation is only one principle which can be applied to the creation of research areas by automatic or pattern recognition processes. There are numerous other methods or measures, such as co-word analysis, journal clustering, bibliographic coupling, citation flows, co-author analysis, etc. which might find application in science indicators. There should be a broader effort to explore these possibilities.

In the last section of Task 2, we experimented with groups of institutions as another organizing principle for new indicators. Instead of focusing on subject matter or field-type categories, this approach aggregates institutions into groups that have some common economic or administrative factor. There are many refinements which could be made in this approach. One would be the weighting of each organization's papers, since it is obvious that not all organizations contribute equally to the citation impact of the group. The strength of the institutional aggregate approach is its flexibility. For example, by grouping institutions according to policy or funding criteria, it would be possible to test the effect those factors have had on research impact.

We have not addressed the use of any of the bibliometric indicators discussed here as predictive models. The most that we can expect at present is an accurate and update description on the current state of science. It is possible that some predictive value will be found in a bibliometric variable, such as the proportion of recent highly cited papers, or the isolation versus integration of a cluster. Most bibliometric indicator efforts suffer from a different problem, the lack of current data. Thus, one goal should be to bring as many indicator efforts as up to date as possible given the availability of the underlying bibliographic databases.

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